Managing olive yield and fruit quality under South African conditions

By
Jacobus Johannes Crous

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Agriculture (Horticultural Science) at the University of Stellenbosch

Supervisor: Dr. Willem Jacobus Steyn
Faculty of AgriSciences
Department of Horticultural Science

December 2012

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date:

ACKNOWLEDGEMENTS

I am grateful to the following people and institutions for their assistance to the successful completion of this study:

My supervisor, Dr Wiehann Steyn, for his expert supervision, constructive criticism, patience and invaluable guidance during my studies.

The Department of Horticultural Science, for financial and administrative support. A special thanks to Dianah Daniels, Carin Pienaar as well as Gustav Lötze and his technical staff for their assistance.

To Cape Olive Trust for financial support, supply of trial sites and field work assistance. A special thanks to John Scrimgeour for his technical insight and practical help.

It is a pleasure to acknowledge my parents; my father for his insight in the olive industry and also setting an example of hard work and encouraging me to never give up; my mother for her consistent prayers, love and support.

To my wife Lorraine, for being more than my best friend; thanks for your support, encouragement and understanding.

My friends and fellow students, for their understanding in times that I could not be with them. A special thanks to Greg, Emil, Hein, Giverson, Bekker, Eugenie-Lien and Marlie. I am also indebted to Michael and Derick for completing the GA trial in my absence.

I am grateful towards Subtrop (my previous employer) and Farmsecure Agri Science (my current employer) who enthusiastically encouraged me to complete this study.

My Saviour Jesus, thanks for guidance through the tough times, for being faithful when I was weak and for giving me life and life in abundance and the ability to successfully complete this study.

SUMMARY

Olives have been produced commercially in the Mediterranean-type climate of the Western Cape region of South Africa since the early 1900's. As in the rest of the world, South African table olive producers struggle with alternate bearing. Naphthalene acetic acid (NAA) has been used since the 1950's to thin table olives in California. To date, South African producers opted to tolerate rather than try to reduce the negative effects of alternate bearing. However, due to increased olive production, profit margins are decreasing and producers can no longer ignore the negative effects of alternate bearing.

Since the efficacy of NAA as a thinning agent is modulated by environmental conditions and genotype, trials were conducted to evaluate the use of NAA on locally important cultivars under South African conditions. The main aim was to establish optimum application rates for 'Barouni', 'Mission' and 'Manzanillo'. NAA decreased the fruit number per tree, thereby improving fruit quality (increased fruit size and a higher proportion black fruit in the case of 'Mission') in all three cultivars. Thinning did not affect the return bloom in any of the cultivars. In the case of 'Barouni', the lack of a return bloom response could be due to the low level of thinning achieved, while climatic conditions during flower development may be to blame for the lack of response in 'Mission' and 'Manzanillo'. Although NAA application did not affect the income per hectare, profitability may increase as harvesting costs account for roughly 50% of the input costs. Based on our results, NAA at 200 mg L^{-1}, applied 10 to 15 days after full bloom, is recommended for local conditions. This concentration is slightly higher than the application rates used in California. An even higher NAA concentration might be used when premium prices are paid for large fruit, as in the case of 'Mission' and 'Manzanillo'. However, NAA at 400 mg L^{-1} seemed to decrease vegetative growth in 'Mission', which may decrease bearing positions for the next season. Earlier application should be considered for a heavy "on" crop while the concentration can be decreased or the spray time delayed to decrease thinning when an average crop is anticipated.

Gibberellic acid (GA_3) was applied during an "off" season to 'Mission' and 'Manzanillo' to determine when during the season floral induction is inhibited by the simulated seed produced hormone. GA_3 had its greatest effect on the extent of flowering in 'Manzanillo'

when applied at the time of endocarp sclerification in early December. It follows from this result that to prevent the negative effects of a crop load on flowering in the subsequent season, thinning has to occur before endocarp sclerification. Later application of GA_3 in January and February also decreased flowering, but to a lesser extent than application in December. These later applications possibly decreased flower initiation in buds on shoots that continued growing for longer or they may also have interfered with flower differentiation. The effect of the reduced "on" crop in the 2010/2011 season in GA_3-treated trees on yield in the 2011/2012 season still needs to be determined.

OPSOMMING

Olywe word sedert die vroeë 1900's kommersieel geproduseer in die Mediterreense tipe klimaat Wes-Kaap streek van Suid Afrika. Soos in die res van die wêreld, is alternerende drag 'n reuse struikelblok vir Suid-Afrikaanse olyfprodusente. Anders as in California waar naftaleenasynsuur (NAA) reeds vanaf die 1950's gebruik word om tafel olywe uit te dun, het Suid-Afrikaanse produsente tot op hede die gevolge van alternerende drag verduur eerder as om die negatiewe effekte daarvan te probeer verminder. Weens 'n afname in winsgewendheid vanweë 'n toename in olyfproduksie kan Suid-Afrikaanse olyfprodusente egter nie meer langer die negatiewe effekte van alternerende drag ignoreer nie.

Die effektiwiteit van NAA as uitdunmiddel word beïnvloed deur omgewingstoestande asook deur die plant se genetika. Gevolglik is proewe onderneem om die gebruik van NAA te evalueer op plaaslik belangrike kultivars en onder Suid-Afrikaanse kondisies. Die hoofdoel van die proewe was om optimale toediening konsentrasies van NAA vir 'Barouni', 'Mission' en 'Manzanillo' te bepaal. NAA het die vruglading per boom verminder en daardeur vrugkwaliteit (vruggrootte asook 'n groter proporsie swart vrugte in die geval van 'Mission') in al drie kultivars verbeter. In al drie kultivars het uitdunning egter geen effek op die volgende seisoen se blom gehad nie. In die geval van 'Barouni' kan die swak opvolgblom moontlik toegeskryf word aan die lae vlak van uitdun terwyl klimaatstoestande tydens blomontwikkeling moontlik die oorsaak was vir die swak reaksie van 'Mission' en 'Manzanillo'. Alhoewel toediening van NAA nie die bruto inkomste per hektaar verhoog het nie, kan winsgewendheid moontlik toeneem aangesien oeskoste ongeveer 50% van insetkostes uitmaak. Gebaseer op die resultate van die studie, word NAA toediening teen 200 mg L^{-1}, 10 tot 15 dae na volblom, aanbeveel vir plaaslike toestande. Hierdie konsentrasie is effens hoër as konsentrasies wat in Kalifornië gebruik word. Selfs hoër NAA konsentrasies kan toegedien word wanneer 'n premium betaal word vir groter vrugte, soos in die geval van 'Manzanillo' en 'Mission'. NAA teen 400 mg L^{-1} het egter vegetatiewe groei in 'Mission' verlaag en dit kan moontlik lei tot 'n vermindering in draposisies in die volgende seisoen. Vroeër toediening moet oorweeg word wanneer 'n groot "aan" oes verwag word, terwyl die NAA konsentrasie verminder of toediening uitgestel kan word ten einde uitdunning te verminder indien 'n gemiddeld oes verwag word .

Gibberelliensuur (GA_3) is in die "af" seisoen toegedien op 'Mission' en 'Manzanillo' om vas te stel wanneer gedurende die seisoen saad-geproduseerde hormone blominduksie inhibeer. Die grootste effek op blominduksie van 'Manzanillo' is verkry met toediening tydens pitverharding gedurende vroeë Desember. Om die negatiewe effek van 'n hoë vruglading op die volgende seisoen se blom te voorkom, moet vruguitdunning dus voor pitverharding geskied. Later toediening van GA_3 in Januarie en Februarie het ook blom verminder, maar tot 'n mindere mate as toediening in Desember. Hierdie later toedienings het moontlik blominisiasie van knoppe wat later gevorm het geïnhibeer of kon moontlik blomdifferensiasie negatief beïnvloed het. Die effek van die verlaagde "aan" jaar in die 2010/2011 seisoen in reaksie op GA_3 toediening op opbrengs in die 2011/2012 seisoen moet nog bepaal word.

TABLE OF CONTENTS

GENERAL INTRODUCTION

Olives have been cultivated for many years in the Mediterranean-type Western Cape region of South Africa. Little research has been conducted on how to optimise table olive production under local conditions.

Olive trees are prone to bear fruit in alternate cycles (Krueger et al., 2004; Lavee, 1996). The heavy crop loads of "on" seasons give rise to fruit of very poor quality while in "off" seasons, the increase in fruit size does not make up for the loss in yield (Krueger et al., 2004). Stutte and Martin (1986) found that the number of seeds present on olive trees negatively correlates with the extent of flower initiation. Decreasing the crop load early in "on" seasons increases fruit quality in the year of application, and also increases the crop load in the subsequent season, thereby reducing the negative effects of yield alternation (Dag et al., 2009). Naphthalene acetic acid (NAA) application at 100 - 150 mg L^{-1} ca. 15 days after full bloom (DAFB) has been used to chemically thin olives in various countries (Lavee, 2006). However, NAA has not been used to thin olives in South Africa. Effective NAA concentrations seem to differ between regions. For example, lower NAA concentrations are used to thin apples in Europe compared to South Africa (Schalk Reynolds, personal communication). Hence, the NAA concentrations used to thin olives in other regions in the world may not necessarily be optimal for South African conditions. Trials were conducted on three olive cultivars that are mainly used for the production of table olives, viz. Mission, Barouni and Manzanillo to establish optimum application rates of NAA that will reduce yield alternation and achieve an optimum balance between yield and fruit quality. 'Barouni' and 'Manzanillo' olives are harvested green for table use only and fruit quality is determined mainly by fruit size. 'Mission' is a dual purpose cultivar. For use as table olives, fruit are harvested black and larger fruit fetch higher prices. Small and green fruit are used for oil production.

In conjunction with the NAA trials, gibberellic acid (GA_3) was applied in "off" seasons to both 'Mission' and 'Manzanillo'. Floral initiation of olives is thought to be suppressed by gibberellic acids (GAs) released by the developing seeds (Fabbri and Benelli, 2000; Lavee, 1996; Stutte and Martin, 1986). The aim of this experiment was twofold; to determine when

flower intiation takes place under local conditions and to evaluate the potential use of GA_3 to reduce yield alternation by decreasing yield in the subsequent “on” year.

At the onset of this study, it was important to obtain sufficient background on the phenology of olive trees for a better understanding of yield alternation and ways to obtain regular yields. Hence, a literature review was conducted focusing on factors connected to the reproductive and vegetative phenology of olive trees.

Literature cited

Dag, A., Bustan, A., Avni, A., Lavee, S. and Riov, J., 2009. Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees. Crop Pasture Sci. 60: 1124 - 1130.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Krueger, W.H., Maranto, J. & Sibbett, G.S., 2004. Olive fruit thinning. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Eds.) Pp. 101-104. University of California, Agriculture and Natural Resources Publication 3353, Oakland, California, USA.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Lavee, S., 2006. Biennial bearing in olive (*Olea europaea L.*). FAO Network. Olea 25: 5-12. July 2006.

Stutte, G.W. & Martin, G.C., 1986. Effect of killing the seed on return bloom of olive. Sci. Hort. 29: 107-113.

LITERATURE REVIEW: ALTERNATE BEARING IN OLIVE WITH REFERENCE TO REPRODUCTIVE DEVELOPMENT

1. INTRODUCTION

The olive (*Olea europaea* L.) is a long-lived evergreen tree that has been cultivated in the Mediterranean basin for thousands of years (Lavee, 1990). Some 'Zutica' orchards have been established over 1000 years ago. One orchard has been reported as being over 2000 years old (Miranovic, 1994). The olive tree prefers a Mediterranean-type climate, i.e., a rainy winter, short spring, hot dry summer and a long autumn (Bongi and Palliotti, 1994). Olives do not survive temperatures below -12 °C, but require a chilling period for flowering (discussed in more detail in section 3.2.2.). Due to these requirements, olives grow best between 25° and 45° latitude North and South of the equator (Bongi and Palliotti, 1994). Commercial olive-production is confined between 30° and 45° (see Table 1 for major producers), and although olive trees grow well at latitudes below 30°, they do not bear much fruit due to insufficient chilling (Rallo and Martin, 1991).

Although olives arrived in the Western Cape province of South Africa in the days of Jan van Riebeeck (late 17th century), the olive industry has only come into being since the 1970's. Factors that contributed to the rapid expansion in the previous four decades include the formation of the South African Olive Growers Association, increased research, an increase in living standards, increased awareness of the health benefits of olive oil, as well as growth in supermarket retailing (Costa, 1998). However, South Africa is still a minor player in world production of olives (see Table 1 for South African olive production relative to the rest of the world).

The main emphasis of this literature review is on alternate bearing, the main problem that besets olive production and also the theme of this thesis. However, the background of the olive, as well as its botany and phenology must first be reviewed to facilitate a discussion on alternate bearing.

Table 1. Major olive producing countries in the world based on 2009 data (FAOSTAT, 2011) in comparison to South Africa (John Scrimgeour, SA Olive, personal communication 2010).

Rank	Country/Region	Production (x 1000 ton)	Cultivated area (x 1000 ha)
—	World	19,302	9,206
1	Spain	7,923	2,500
2	Italy	3,287	1,190
3	Greece	1,963	646
4	Turkey	1,291	727
5	Syria	886	636
6	Morocco	770	550
7	Tunisia	750	1,500
8	Egypt	500	110
9	Algeria	475	288
10	Portugal	363	381
?	South Africa	10	2.5

2. BOTANY OF THE OLIVE

2.1. Flowers

Mature olive trees produce ~500 000 flowers of which only 1-2% set fruit that reach maturity (Lavee, 1996). Usually about 10-15% of the flowers set at first, but further fruit drop takes place 3 to 5 weeks after full bloom until the final fruit number (~1-2% of flowers) is reached 6 to 7 weeks after full bloom (Lavee, 1986). The rapid abortion of flowers following successful fertilization on individual inflorescences reduces wasteful tissue growth (Martin,

1994). Inflorescences develop mostly in the axils of leaves. Reproductive buds are formed on the current season's growth, but only begin visible growth the next season (Pinney and Polito, 1990). Each inflorescence may contain 15 to 30 flowers (Martin and Sibbett, 2004). The number of flowers as well as their distribution on the inflorescence is specific for each cultivar, but also varies from year to year (Lavee, 1996).

Olive flowers are small and white. Each contains four fused green sepals, four white petals, two stamens, each with a large yellow anther, and two carpals, each with two ovules (Lavee, 1996). Flowers are mostly either hermaphroditic (bisexual/ perfect) or staminate (male). Perfect flowers have a stamen and pistil, whereas staminate flowers have aborted pistils but functional stamens (Martin et al., 2004). More staminate flowers are usually present than perfect flowers (Martin and Sibbett, 2004). The proportion of perfect and staminate flowers is cultivar dependent and is affected by climatic conditions and the previous year's crop load – fewer perfect flowers after an "on" year (Reale et al., 2006). Both perfect and staminate flowers produce viable pollen grains, but only perfect flowers have the ability to set fruit (Reale et al., 2006). However, only one perfect flower per inflorescence is required to attain sufficient yields (Lavee, 1996).

2.2. Fruit

The olive fruit is a drupe where the fruit consists of the carpals, and the wall of the ovary has both fleshy and dry portions. The skin (exocarp) contains stomata and is free of hair. The flesh (mesocarp) is underneath the skin and surrounds the pip (endocarp), which encloses a single seed (Martin, 1994). Olive fruit growth follows a double sigmoid pattern (Lavee, 1986, 1996).

3. PHENOLOGY

3.1. Floral induction

Floral induction (FI), i.e. changes in gene expression and chemical changes in the meristem that gives the plant the ability to flower, occurs in mid-summer (7 to 8 weeks after full bloom) at the approximate time of pit hardening of the current season's fruit (Fernandez-Escobar et al., 1992; Sanz-Cortés et al., 2002). Stutte and Martin (1986b) found that seed

destruction prior to endocarp sclerification (pit hardening) promoted flower formation compared to seeded controls. Hence, floral induction is apparently influenced by compounds released by the developing fruit and seeds and translocated to the buds (Fabbri and Benelli, 2000; Lavee, 1996; Stutte and Martin, 1986b). Induction cannot be observed visually, but Navarro et al. (1990) found significant higher amounts of RNA in buds of non-bearing trees than in buds of bearing trees in mid-summer. He also found an increase in bud size of non-bearing as compared to bearing trees as early as August (February in Southern Hemisphere). Flower bud induction had to precede the above changes. Lavee (1996) concluded from his previous work that initial induction takes place in the summer. The degree of differentiation potential is depended on the vegetative growth as well as the fruiting history of the tree. A second induction of differentiation, which is dependent on low temperature, takes place in the winter.

Scaffold injections of gibberellic acid (GA_3) between May and November (during endocarp sclerification in the Northern Hemisphere) to non-bearing olive trees, reduced flowering the following year (Fernandez-Escobar et al., 1992), lending support to the hypothesis that FI takes place in the previous season. Exogenous applications of gibberellins inhibit flowering in some fruit tree species like the apple (Bangerth, 2006) and persimmon (Steyn et al., 2008). Results by De la Rosa and Rallo (2000) and Fabbri and Benelli (2000), however contradicted the above findings. They have seen no bud activity and have found that the modifications within the buds were very slight, if at all, until December (winter in the Northern Hemisphere).

3.2. Floral initiation

3.2.1. Timing of floral initiation

Flower initiation is defined as the first stage when flower buds can be identified by histochemical or biochemical tests (Gucci and Cantini, 2000). Floral initiation is considered to have taken place when floral tissues are first evident in developing buds. According to most olive researchers, flower initiation occurs between the end of the summer and autumn (Gucci and Cantini, 2000). Pinney and Polito (1990) found no visible macroscopic or microscopic differences between buds of bearing and non-bearing trees until mid-October (mid-April in Southern Hemisphere). Although buds increased in size from mid-October to

mid-November (mid-April to mid-May in Southern Hemisphere), they remained anatomically undifferentiated.

3.2.2. Chilling pre-requisite for flowering

According to research conducted more than forty years ago, chilling is a pre-requisite for floral initiation in olive (Hartmann, 1953). This implied that vernalisation was the final inductive step towards floral initiation. Stutte and Martin (1986a) also initially suggested that endogenous factors, such as a requirement for winter chilling, play a very important role in floral initiation. However, after further study, Stutte and Martin (1986b) indicated that chilling may not play a role in floral initiation, since floral initiation for the return bloom may already occur just after anthesis in the current season. Further work by Pinney and Polito (1990) and Rallo and Martin (1991) suggest that winter chilling is required to complete floral differentiation and to release flower buds from dormancy.

3.3. Floral differentiation

3.3.1. Timing of differentiation

The induction phase is a range of modifications in the bud that ultimately 'commits' it to the possibility of the formation of reproductive structures. This is also known as the 'irreversible' stage (Lavee, 1996). If a certain bud wasn't induced as a possible flower, but rather remained a vegetative bud, it cannot differentiate to become reproductive at a later stage. Subsequently, the bud either develops further into a flower bud, or does not to undergo any further reproductive development and thus remains vegetative. After the 'irreversible' stage, the bud is 'induced' to flower and ready to begin the next phase, termed differentiation (Fabbri and Benelli, 2000).

A two-step theory has been suggested for olive flower bud differentiation (Lavee, 1996). The assumption is made that buds receive their initial stimulus for differentiation in the summer while a second stimulus is required during winter. According to these assumptions, differentiation will only occur if inductive conditions prevail in both seasons (Lavee, 1996). Buds receive the initial stimulus for potential reproductive differentiation while active growth takes place in the tree. Both endogenous factors as well as fruiting history of the tree have an influence on flower bud development. Differentiation of flower buds is also very dependent

on environmental conditions such as chilling or day/night temperature alterations during the winter period (Lavee, 1996). Pinney and Polito (1990) further suggested that buds that formed later during the growing season (just before winter) can also become reproductive, but the flower quality might not be as good as in buds that developed earlier during the growing season.

Buds that may give rise to flowers are between 3 and 8 months old. Buds in the axils of the most distal leaves (growth that occurred just before winter) normally does not undergo floral differentiation (Lavee, 1996).

3.3.2. Optimum temperatures for floral differentiation

It has long been known that olives require low temperatures during winter for flowering in spring. However, low temperatures *per se* will not necessarily ensure a crop. Olive trees grown at a constant temperature of 12.5 °C produced flowers, but these flowers were imperfect, i.e., lacking pistils (Badr and Hartmann, 1971). In further trials, maintaining trees at a constant temperature of 7 °C or 15 °C prevented flower formation (Hartmann and Whisler, 1975). Denney and McEachern (1983) found that in California, optimum flowering occurred when the temperature fluctuated between 15.5 to 19 °C (maximum) and 2 to 4 °C (minimum) in mid-winter.

Rallo and Martin (1991) subjected trees to 4 weeks of chilling at 7.2 °C or 12.5 °C. This was followed by 6 weeks of alternating temperatures (10/21 °C), 6 weeks of chilling at 7.2 °C or 12.5 °C followed by 4 weeks of alternating temperatures (10/21 °C) or 10 weeks at alternating temperatures (10/21 °C). Since shoots were collected during mid-winter, some chilling already accumulated prior to treatment. Trees did not produce any flowers while chilled at 7.2 °C, but as soon as the trees were exposed to temperatures that normally promote bud growth (10/21 °C), flowers were formed rapidly. As found by Denney and McEachern (1983), it seems that 4 weeks at 7.2 °C were sufficient to meet the chilling requirements for flowering . Flowering also occurred in response to chilling at 12 °C for 4 weeks, but was delayed. Trees kept at 10/21 °C for the entire 10-week duration of the trial developed fewer flowers and flowering was delayed and protracted indicating that this temperature regime did not overcome the chilling requirement of olive buds. This is also in agreement with De Melo-Abreu et al. (2004) who found that relatively warm day temperatures (23.6 ºC) during winter

negated the stimulating effect of chilling (7.9 ºC) on flowering. Flowering was advanced by constant chilling at 12.5 °C, but the flowers were of poor quality (De Melo-Abreu et al., 2004). Hence, it seems that this temperature meets the chilling requirements to overcome dormancy as well as to promote growth of chilled buds, but does not necessarily meet the differentiation requirements (Denney and McEachern, 1983). Badr and Hartmann (1971) calculated that 12.5 °C is a 'compensation point' where night temperatures are cold enough to accumulate chilling units and day temperatures warm enough for cell division. The compensation point is also achieved at a diurnal temperature combination of 7 °C and 18 °C. In contrast to flower buds, vegetative buds seem to have very little if any dormancy since they grow whenever temperatures are above 21 °C (Martin, 1994).

Cultivars seem to differ in their chilling requirement (hours between 2 and 7.2 °C). 'Arbequina' (Malik and Bradford, 2005) and 'Manzanillo' (Rallo and Martin, 1991) required 0 and 800 hours at the effective temperature range, respectively, to bear optimal yield.

4. ALTERNATE BEARING

4.1. Background

Alternate bearing is a widespread phenomenon in many fruit trees (Monselise and Goldschmidt, 1982). Olive trees are well known to produce crops in alternate-year cycles (see Figure 1 for an example of alternation in olive). Alternate bearing is a two year cycle consisting of an "on" and "off" season. "On" seasons are characterized by heavy crops and are then followed by an "off" season during which very little or no crop is produced. Strong vegetative growth occurs during the "off" season thus providing abundant bearing sites for the next season's crop (Krueger et al., 2004). The "on" season that follows is characterised by an abundance of flowers, a huge set, small fruit size, delayed fruit maturity, little vegetative growth and, therefore, less bearing positions for the next season's crop, as well as low floral induction (Lavee, 1996).

Although the olive is genetically predisposed to alternate bearing, climatic conditions can have a large effect on its expression (Hackett and Hartmann, 1967). Secondary causes of alternate bearing include cultural practices that diminish olive tree vigour, for example, lack

of nutrients and drought stress (Martin et al., 2004). This review will predominantly focus on the primary causes of alternation.

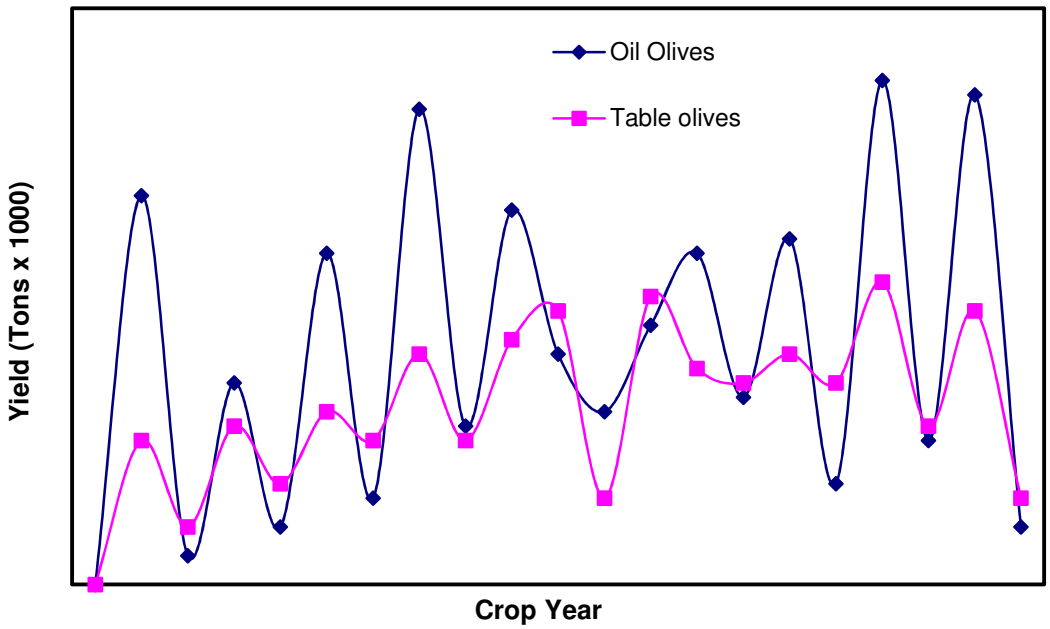


Fig. 1. Schematic representation of an established alternate bearing cycle in oil and table olive orchards in Israel adapted from Lavee (1996).

4.2. Environmental effects

Alternation can either develop gradually as trees come into production or commence more suddenly due to a climatic trigger (Goldschmidt, 2005). In the first case, some trees in an orchard will be in the "on" cycle while other trees in the same orchard may experience an extreme ''off'' season. In contrast, alternation is usually synchronised throughout the orchard if induced by environmental events.

Olive fruit set is greatly climate dependant. Only one fruit per inflorescence will usually set. Any environmental stress when the fruit are on the tree may induce abscission of fruit. Cool spring conditions may, however, increase fruit set to five to seven fruit per inflorescence (Lavee, 1986). This increased initial set does not, however, significantly increase the final fruit number per tree, due to increased natural fruit drop/abscission happening only at a later stage. High temperatures at flowering do not necessarily interfere with fruit set. However, a

combination of low humidity and high temperatures may cause abnormally high abortion of embryos and drying out of young fruitlets (Lavee, 1986).

Climatic factors may increase alternate bearing in some regions. Since successful reproductive development (differentiation) is dependent on winter chilling, an "off" season can be induced when conditions are unfavourable for flower development. Pinney and Polito (1990) and Rallo and Martin (1991) suggested that winter chilling is necessary for differentiation of high quality flower buds. Trees exposed to insufficient chilling did flower, but the flowers were of low quality and had a low set percentage as explained in section 3.2.3. Briccoli Bati et al. (2002) found that olive fruit set decreased with an increase in the number of hours above 27 °C during winter.

4.3. Carbohydrates

Sugar and starch levels are much higher at the beginning of an "on" than an "off" season (Fahmy, 1958). More to the point, sugar and starch levels in olive leaves are much higher after a non-bearing than after a bearing year (Nejad and Niroomand, 2007). The high crop load of an ''on'' season draws on carbohydrate reserves stored in the tree. Hence, large crops reduce carbohydrate levels available to differentiating flower buds, flowers and young fruits. High fruit set and low fruit abscission are reliant upon the availability of sufficient carbohydrate reserves in apples (Stopar et al., 2000) and citrus (Goldschmidt, 1999). The availability of carbohydrates seems to be of lesser importance for flower formation in olive (Stutte and Martin, 1986b). Hence, low carbohydrate levels after an "on" season is not a direct cause of alternate bearing in olive (Hackett and Hartmann, 1964). In olive, reproductive organs appear to have higher sink strength than vegetative organs (Rallo and Suarez, 1989). It was further concluded that heavy crops receive resources at the expense of shoot growth (Krueger et al., 2004). A reduction in shoot growth decreases potential bearing positions for the next season, since the olive bear its fruit on one-year-old shoots (Lavee, 1996).

4.4. Phenolic acids

Higher levels of chlorogenic acid (CHA) accumulate in olive leaves in "on'' than in "off'' seasons (Lavee and Avidan., 1981). Removal of young fruitlets after set prevents

accumulation of CHA in the leaves and results in good flower differentiation and bloom in the following season (Lavee et al., 1986). Injection of CHA before winter into olive trees significantly decreases flower bud differentiation (Lavee et al., 1986). However, when CHA injections occurred later than mid-winter, flower differentiation and fruit set were not affected (Lavee et al., 1986). This shows that CHA has a direct effect on flower formation in olive that is not due to toxicity.

4.5. Hormones

4.5.1. General influence on alternate bearing

To counteract alternate bearing or to produce fruit in the "off" season, the key to success is the ability to control flower induction (Bangerth, 2006). Besides the role of carbohydrates as explained earlier, plant hormones are very important in controlling the shift from vegetative to generative bud development (Bernier et al., 1993). Of the various endogenous substances that have been investigated so far, plant hormones were most consistently found to have a close relationship with floral induction (Bangerth, 2006).

4.5.2. Seeds

Flower induction is suppressed by high fruit loads through the gibberellic acids (GAs) released by the developing seeds (Fabbri and Benelli, 2000; Lavee, 1996; Stutte and Martin, 1986b). Chan and Cain (1967) showed that seedless apple fruit do not have the same inhibitory effect on floral induction of nearby shoot meristems as seeded fruit. The importance of seed in alternate bearing has been confirmed for a number of other tree species (Marine and Greene, 1981; Ebert and Bangerth, 1981). An inhibitory signal originates in the seeds and is then transported to nearby shoot meristems where it prevents floral induction (Bangerth 1997).

4.5.3. Hormonal interactions

It is thought that seeds exert their effect on flower development through GAs (Bangerth, 1997), of which they are a rich source (Steffens and Hedden, 1992). Exogenous application of GAs can also inhibit floral induction, further implicating these hormones as the most likely candidates for the seed signal. Apparently GAs, as primary messengers involved in flower

induction, remains in the seeds or shoot tips where they stimulate auxin (IAA) synthesis/transport. IAA, as secondary messenger, suppresses flower induction (Bangerth, 1997). The above hypothesis is supported by the finding that application of GAs stimulates polar IAA transport out of fruit and shoot tips (Kuraiski and Meier, 1962).

IAA concentration and/or transport may be linked to the inhibition of floral induction in annual plants (Bernier et al., 1993) and further relate to correlative effects such as apical dominance. An increase in apical dominance in a tree means that the IAA stream of the inhibitory organ increases at the expense of the IAA streams of inhibited organs (Bangerth, 1989). A smaller IAA stream goes hand-in-hand with a general smaller transport system for assimilates, water, minerals and other compounds necessary for floral induction (Daie, 1985). The removal of very young leaves in apple shoots, which prevents apical dominance, indeed stimulated floral induction in lateral buds of these shoots (Tsujikawa et al., 1990). Further convincing evidence that IAA is a floral induction inhibitory signal was obtained with the observation that application of IAA-transport inhibitors, such as 2,3,5-triiodobenzoic acid (TIBA), stimulated floral induction in annual as well as perennial plants (Tsujikawa et al., 1990).

Most inhibitors of GA-biosynthesis also to some extent reduce the export of IAA from fruit and shoot tips (Ebert and Bangerth, 1981). Paclobutrazol have been found to interfere with the biosynthesis of GAs by preventing the oxidation of kaurene to kaurenic acid (Dalziel and Lawrence, 1984). In doing so, it inhibits GA-biosynthesis in the sub-apical meristem (Hedden and Graebe, 1985). Foliar applications of this inhibitor enhanced fruit bud differentiation and yield in the second year by more than 50% in apples (Sansavini et al., 1986). In contrast, scaffold injection of paclobutrazol had no significant effect on return bloom, final fruit set or fruit size in Manzanillo olive (Fernandez-Escobar et al., 1992).

Cytokinins stimulate floral induction in annual as well as perennial plants. These hormones have been shown to be positively involved in floral induction (Bernier et al. 2002). Molecular biologists have repeatedly found that high IAA concentrations often depress the cytokinin concentration of a particular organ (Muday and DeLong, 2001). IAA transport as well as IAA concentration is important in influencing the concentration of cytokinins.

Bangerth (2006) suggested that an optimum concentration of cytokinins is necessary to enable the meristem to produce flowers, probably due to the stimulatory effect of cytokinins on meristematic activity (cell division). Too low activity generally results in some kind of dormancy, while too high activity may give rise to a new vegetative flush (Bangerth, 2006). It seems that a critical cytokinin concentration in a resting, but not dormant, meristem is needed for floral induction (Bangerth, 2006).

5. CONCLUSION

A continuous and complex interaction between temperature and other environmental factors are involved in both the vegetative and reproductive development of olive buds (Lavee, 2006). An increase in fruit number, thus seeds, will increase GAs which will further accentuate the negative effect of IAA on flower induction. IAA suppresses flower induction through a direct signal or indirectly by a negative effect on cytokinins. The crop potential of the next season can be assured to a certain degree by removal of fruit before seed-produced GAs become influential.

Although the olive is genetically predisposed to alternate bearing, it can be managed and controlled by horticultural practices. Alternate bearing is controlled by the interaction of fruit load and vegetative growth. Since the olive bear its fruit on one year-old wood, shoot growth must occur in order to produce sufficient flowering sites. Hence, it is important to maintain a good balance between fruit load and shoots/vegetative growth. Horticultural intervention via pruning, thinning, girdling and other cultural and nutritional means can reduce and even eliminate alternate bearing in favourable climatic conditions, but under unstable environmental conditions alternate bearing is very difficult to control.

6. LITERATURE CITED

Badr, S.A. & Hartmann, H.T., 1971. Effect of diurnally fluctuating vs. constant temperatures on flower induction and sex expression in the olive (*Olea europaea* L.). Physiol. Plant. 24: 40–50.

Bangerth, F., 1989. Dominance among fruits/sinks and the search for a correlative signal (Mini-review). Physiol. Plant. 76: 608-614.

Bangerth, F., 1997. Can regulatory mechanism in fruit growth and development be elucidated through the study of endogenous hormone concentrations? Acta Hort. 463: 77-87.

Bangerth, F., 2006. Flower induction in perennial fruit trees: Still an Enigma? Acta Hort. 727: 177-195.

Bernier, G., Havelange, A., Houssa, C., Petitjean, A. & Lejeune, P., 1993. Physiological signals that induce flowering. Plant Cell 5: 1147-1155.

Bernier, G., Corbesier, L., & Perilleux, C., 2002. The flowering process: on the track of controlling factors in *Sinapis alba*. Russ. J. Plant Physiol. 49: 445-450.

Bongi, G. & Palliotti, A., 1994. Olive. Pg. 165-187. In: B. Schaffer and P.C. Anderson (Eds.). Handbook of environmental physiology of fruit crops. CRC Press, Boca Raton, Florida, USA.

Briccoli Bati, C., Filipucci, B. & Monardo, D., 2002. Bioclimatology of olive: Effects of climatic conditions on flower biology. Acta Hort. 586: 493-495.

Chan, B.G. & Cain, J.C., 1967. The effect of seed formation on subsequent flowering in apple. Proc. Amer. Soc. Hort. Sci. 91: 63-68.

Costa, C., 1998. Olive production in South Africa. ABC Press, Stellenbosch, South Africa.

Daie, J., 1985. Carbohydrate partitioning and metabolism in crops. Hort. Rev. 7: 69-99.

Dalziel, J. & Lawrence, D.K., 1984. Biochemical and biological effects of kaurene oxidase inhibitors such as paclobutrazol. Brit. Plant Growth Reg. Group. 11: 43-57.

De la Rosa, R. & Rallo, L., 2000. Olive floral bud growth and starch content during winter rest and spring budbreak. HortSci. 35: 1223-1227.

De Melo-Abreu, J.P., Barranco, D., Cordeiro, A.M., Tous, J., Rogado, B.M. & Villalobos, F.J., 2004. Modeling olive flowering date using chilling for dormancy release and thermal time. Agri. For. Meteorol. 125: 117-127.

Denney, J.O. & McEachern, G.R., 1983. An analysis of several climatic temperature variables dealing with olive reproduction. J. Am. Soc. Hort. Sci. 108: 578-581.

Ebert, A. & Bangerth, F., 1981. Relations between the concentration of diffusible and extractable gibberellin-like substances and the alternate bearing behavior in apple as affected by chemical fruit thinning. Scientia Hort. 15: 45-52.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Fahmy, I., 1958. Changes in carbohydrate and nitrogen content of Souri olive leaves in relation to alternate bearing. Proc. Am. Soc. Hort. Sci. 72, 252-256.

Fernández-Escobar, R., Benlloch,M., Navarro,C. & Martin, G.C., 1992. The time of floral induction in olive. J. Am. Soc. Hort. Sci. 117: 304-307.

FAOSTAT. Latest (2009) data. Available at: http://faostat.fao.org/site/567/Desktop Default.-aspx?PageID=567#ancor. Accessed 31/05/2011.

Goldschmidt, E.E., 1996. Reproductive physiology. Pp. 70-125. In: Spiegel-Roy and E.E. Goldschmidt (Eds.), Biology of Citrus. University Press, Cambridge, England.

Goldschmidt, E.E., 1999. Carbohydrate supply as a critical factor for Citrus fruit development and productivity. HortSci. 34: 1020-1024.

Goldschmidt, E.E., 2005. Regulatory aspects of alternate bearing in fruit trees. Abstract. Italus Hortus. 12: 11-12.

Gucci, R. & Cantini, C., 2000. Basic principles for pruning woody crops. In: Pruning and training systems of modern olive growing. Pp. 17. CSIRO Publishing. Collingwood, Australia.

Hackett, W.P. & Hartmann, H.T., 1964. Inflorescence formation in olive as influenced by low temperature, photoperiod and leaf area. Bot. Gaz. 125: 65-72.

Hackett, W.P. & Hartmann, H.T., 1967. The influence of temperature on floral initiation in the olive. Physiol. Plant. 20: 430-436.

Hartmann, H.T., 1953. Effect of winter chilling on fruitfulness and vegetative growth in the olive. Proc. Amer. Soc. Hort. Sci. 62: 184-190.

Hartmann, H.T. & Whisler, J.E., 1975. Flower production in olive as influenced by various chilling temperature regimes. J. Am. Soc. Hort. Sci. 100: 670-674.

Hedden, P. & Graebe, J.E., 1985. Inhibition of giberellin biosynthesis by paclobutrazol in cell-free homogenates of Cucurbita maxima endosperm and malus pumila embryos. J. Plant. Growth Reg. 4: 111-122.

Krueger, W.H., Maranto, J. & Sibbett, G.S., 2004. Olive fruit thinning. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Eds.) Pp. 101-104. University of California, Agriculture and Natural Resources Publication 3353, Oakland, California, USA.

Kuraiski, S. & Meier, R.M., 1962. Increase in diffusible auxin after treatment with gibberellin. Sci. 137: 760-761.

Lavee, S., 1986. Olive. In: CRC Handbook of Fruit Set and Development. Monselise, S.P. (Ed.) Pp. 261-276. CRC Press. Boca Raton, Florida, USA.

Lavee, S. & Avidan, N., 1981. Possible involvement of chlorogenic acid in controlling alternate fruiting of the olive. Proc. 13th Int. Bot. Cong. Sydney Australia. Pp. 62.

Lavee, S., Harshemesh, H. & Avidan, N., 1986. Phenolic acids - Possible involvement in regulating growth and alternate bearing in olive trees. Acta Hort. 179: 317-328.

Lavee, S., 1990. Aims, methods, and advances in breeding of new olive (*Olea europaea* L.) cultivars. Acta Hort. 286: 23-36.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Lavee, S., 2006. Biennial bearing in olive (*Olea europaea L.*). FAO Network. Olea 25: 5-12. July 2006.

Malik, N.S.A. & Bradford, J.M., 2005. Is chilling a prerequisite for flowering and fruiting in 'Arbequina' Olives? Int. J. Fr. Sci. 5(3): 29-39.

Marine, F. & Greene, D.W., 1981. Involvement of gibberellins in the biennial bearing of 'Early McIntosh' apples. J. Amer. Soc. Hort. Sci. 106: 593-596.

Martin, G.C., 1994. Olea europaea L. Available at http://www.nsl.fs.fed.us/wpsm/ Olea.pdf. Accessed 20/09/2008.

Martin, G.C., Ferguson, L. & Sibbett, G.S., 2004. Flowering, Pollination, Fruiting, Alternate Bearing, and Abscission. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Eds.) Pp. 49-54. University of California, Oakland, California, USA.

Martin, G.C. & Sibbett, G.S., 2004. Botany of the Olive. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Eds.) Pp. 15-18. University of California, Oakland, California, USA.

Miranovic, K., 1994. Investigations of elayographic properties of the olive cultivar Zutica (*Olea europaea* L.). Acta Hort. 356: 74-77.

Monselise, S.P. & Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. Hort. Rev. 4: 128-173.

Muday, G.K., & DeLong, A., 2001. Polar auxin transport: controlling where and how much. Trends Plant Sci. 11: 535-542.

Navarro, C., Fernández-Escobar, R., & Benlloch, M., 1990. Flower bud induction in Manzanillo olive. Acta Hort. 286: 195-198.

Nejad, M.S. & Niroomand, A., 2007. Carbohydrate content and it's roles in alternate bearing in olive. Pak. J. Bio. Sci. 10 (16): 2744-2747.

Pinney, K. & Polito V.S., 1990. Flower initiation in Manzanillo olive. Acta Hort. 286: 203-205.

Rallo, L. & Martin, G.C., 1991. The role of chilling in releasing olive floral buds from dormancy. J. Am. Soc. Hort. Sci. 116: 1058-1062.

Rallo, L. & Suarez, M.P., 1989. Seasonal distribution of dry matter within the olive fruit-bearing limb. Adv. Hort. Sci. 3: 55-59.

Reale, L., Sgromo, C., Bonofiglio, T., Orlandi, F., Fornaciari, M., Ferranti, F & Romano, B., 2006. Reproductive biology of olive (*Olea europaea L.*) DOP Umbria cultivars. Sex Plant Reprod. 19: 151-161.

Sansavini, S., Bonomo, R., Finotti, A & Palara, U., 1986. Foliar and soil application of paclobutrazol on gloster apple. Acta. Hort. 179: 489-496.

Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., & Meier, U., 2002. Phenological growth stages of olive trees (*Olea europaea*). Ann. Appl. Biol. 140: 151-157.

Steffens, G.L. & Hedden, P., 1992. Comparison of growth and gibberellin concentrations in shoots from orchard-grown standard and thermosensitive dwarf apple trees. Physiol. Plant. 86: 544-550.

Steyn, W.J., Ungerer, S.F. & Theron, K.I., 2008. Scoring and girdling, but not GA_3, increase yield without decreasing return bloom in 'Triumph' persimmon. HortSci. 43: 2022-2026.

Stopar, M., Gregor, A. & Bati, F., 2000. Apple fruit abscission is influenced by assimilate supply. Acta. Hort. 527: 169-178.

Stutte, G.W. & Martin, G.C., 1986a. Effect of light intensity and carbohydrate reserves on flowering of olive. J. Am. Soc., 111: 27-31.

Stutte, G.W. & Martin, G.C., 1986b. Effect of killing the seed on return bloom of olive. Sci. Hort. 29: 107-113.

Tsujkawa, T., Ichii, T., Nakaniski, T., Ozaki, T. & Kawai, Y., 1990. In vitro flowering of japanese pear and the effect of GA4+7. Sci. Hort. 41: 233-245.

Paper 1. Evaluate the use of NAA to thin 'Barouni' olives in the "on'' year to increase fruit quality and to decrease alternate bearing under South African conditions.

Abstract. Alternate bearing is one of the major challenges facing olive growers. High fruit set in an "on" season decreases flower initiation thereby resulting in a subsequent "off" season. Early fruit thinning in an "on" season with naphthalene acetic acid (NAA) is used in some olive growing countries to reduce fruit numbers and increase fruit size in the "on" season, and to ensure adequate fruit numbers in what otherwise would have been the subsequent "off" season. However, NAA has not been used for olive thinning in South Africa and the effective concentrations for local conditions and cultivars are not known. 'Barouni' olives are grown for table purposes only as the amount of oil accumulated in fruit are low. Therefore, fruit quality is determined mainly by fruit size. In the current study, NAA was applied to 'Barouni' olive trees at 100, 150 and 200 mg L^{-1} in the 2007/08 season. NAA on average decreased the estimated total fruit number by 19.1% and reduced yield by 11.8%. The decrease in fruit numbers resulted in a significant increase in fruit size – the percentage fruit in the jumbo (>5.4 g) category was 9.9% higher compared to the control. Although there was no differential payment according to fruit size in the 2007/2008 season, the increase in fruit size is important since larger 'Barouni' olives generally sells for higher prices. Despite a significant decrease in yield and increase in fruit size compared to the control, the subsequent "off" season yield (2008/09) was not affected by any of the treatments. This was probably due to the mild thinning effect of the NAA concentrations evaluated. In summary, it seems that effective NAA concentrations for optimal thinning of 'Barouni' under South African conditions might be higher compared to optimal concentrations (120 - 150 mg L^{-1}) used in California.

Introduction

Olives are well known to produce crops in alternate-year cycles (Krueger et al., 2004; Lavee, 1996). Yield may alternate from 0 ton ha^{-1} in "off" season to 30 ton ha^{-1} in "on" season (Lavee, 1996). The heavy crop loads of "on" seasons give rise to fruit of a very poor quality (i.e., small fruit size in the case of 'Barouni' and other table olive cultivars) (Krueger et al., 2004). Hence, alternate bearing causes significant loss of income since fruit are too small for use as table olives in an "on" season (Lavee, 2006) while in an "off" season, the increase in fruit size does not make up for the loss in yield (Krueger et al., 2004). Alternate

bearing also creates challenges with regard to the horticultural farming practices, planning labour and operating and utilizing storage and processing facilities (Monselise and Goldschmidt, 1982).

The number of seeds present on olive trees correlates negatively with the extent of flower initiation (Stutte and Martin, 1986). Developing seeds and fruits produce high levels of gibberellic acids (GAs) that negatively affect flower initiation (Fabbri and Benelli, 2000; Lavee, 1996). Apart from the direct negative effect of seeds on flower initiation, a heavy crop load may also decrease fruiting positions for the next season's crop, by reducing vegetative growth. The heavy crop load of an "on" season is a very strong carbohydrate sink that receives resources at the expense of shoot growth (Lavee, 1996). It was further concluded that developing fruit in the present year not only compete with the vegetative growth, but also have a direct effect on reproductive induction and differentiation of the buds for the potential yield the following year. Since flowers exclusively form on one-year-old shoots, the decrease in vegetative growth in an "on" season may also contribute to a low crop in the next season (Lavee, 1996).

To overcome biennial bearing and to obtain adequate fruit quality, excessive crops must be reduced early during the "on" season. Flower induction in olive occurs as early as 7 to 8 weeks after full bloom (FB) at approximately the same time of endocarp sclerification (pit hardening) of the current season's fruit (Baktir et al., 2004; Fernández-Escobar et al., 1992; Sanz-Cortés et al., 2002). Fruit removal after flower initiation does not have a positive effect on flower abundance in the subsequent season, but only affects the quality of the current crop (Williams and Fallahi, 1999).

Reducing the crop load by fruit thinning is more effective than reducing it through pruning. This is because fruit thinning increases, whereas pruning maintains, the leaf to fruit ratio (Krueger et al., 2004). Fruit thinning is an established management technique to improve fruit quality and reduce alternate bearing in various fruit crops (Link, 2000). In olive, fruit thinning ca. 2 weeks after FB was found to increase vegetative growth, flower bud differentiation, fruit size and yield (Dag et al., 2009; Lavee, 2006; Martin et. al., 1994).

The synthetic auxin, naphthalene acetic acid (NAA), has been used to thin olives in California since the 1950's (Hartmann, 1952). NAA application at 100 - 150 mg L^{-1} ca. 15 days after FB successfully thins and reduces alternation in various olive cultivars with positive effects on return bloom (Lavee 2006) and fruit quality, i.e., fruit size, flesh-to-pit ratio and oil content (Martin et al., 1980). Since flowering after NAA application has been found to be more abundant than expected on the basis of thinning alone, NAA may also have a direct stimulating effect on flower initiation (Harley et al., 1958). NAA application in the "off" season was also found to stimulate flower-bud formation in alternate bearing apple trees (Harley and Regeimbal, 1959).

To date, South African olive producers have not thinned fruit, but rather tolerated the negative effects of alternate bearing. However, escalating operational costs and increasing competition make it impossible to longer ignore the negative effect of yield alternation on profitability. Since the effectiveness of NAA is known to be modulated by environmental conditions (Hartmann, 1951) and genotype (Krueger et al., 2004), the trials reported here were initiated to evaluate the use of NAA and to establish optimum application rates for local conditions for 'Barouni'.

Material and Methods

Plant material.

The experiment was conducted in the 2007/2008 season at Paarl (Latitude 33°45'S, Longitude 18°56'E) in the Mediterranean-type climate Western Cape Province of South Africa in a 'Barouni' orchard planted in 1991 at a spacing of 9 x 4.5 m. Trees have an average canopy volume of 40 m^3.

Treatments.

NAA (Planofix, Bayer CropScience AG, Isando, South Africa) was applied at 100, 150 and 200 mg L^{-1} 15 days after full bloom (DAFB) on 31 October 2007 at an average fruit size of 3.4 mm. Treatments, including an untreated control, were randomized in 10 blocks with two trees per plot, guard trees between plots and guard rows between treatment rows. NAA was applied early on windless mornings with a truck-mounted motorized sprayer until drip

off. Each tree received ca. 6 L of the spray mixture. No wetting agent was used as per Bayer CropScience recommendation.

Fruit set.

Three one-year-old shoots of about 20 cm long (ca. 15 fruit per shoot) per tree were selected and the number of fruit per shoot counted on the day of NAA application. Fruit were counted again on 18 January 2008 after the fruit drop period and fruit set was calculated.

Fruit quality at harvest.

Trees were harvested twice, on 6 and 24 March 2008. Only fruit that exceeded an estimated minimum size (harvesters are trained to select the biggest fruit) were picked during the first selective harvest while all remaining fruit were harvested 18 days later. All fruit were weighed to determine yield in kg per tree, subsequently converted to ton ha^{-1}. A 20-fruit sample per treatment plot was randomly collected on each harvest date to determine average fruit and pip diameter (measured by electronic calliper), the pip-to-flesh ratio and average fruit weight. Fruit number per tree was estimated by dividing the total fruit weight per tree by the average fruit weight of the 20-fruit sample.

Economic analysis.

'Barouni' olives are divided into four size categories according to industry size standards, viz jumbo (>5.4 g), large (4.55 – 5.4 g), medium (4 – 4.55 g) and small (<4 g). To determine the percentage of fruit per size category according to fruit weight, the average fruit diameters and average fruit weights of treatment replications were plotted and a linear regression line fitted to the data. Individual fruit weights of the 20 fruit per treatment replicate were determined by inserting fruit diameters into the equation obtained from the regression line. Jumbo, large and medium fruit were sold for the same price (R8.80 / kg) in 2007/2008, whereas small fruit were sold for oil at a much lower price (R1.50 / kg) (Scrimgeour, personal communication 2010). Yield per category, income per category and category distribution were determined. Income per ha was determined for each treatment by adding the incomes per category for each treatment.

Vegetative growth.

All new vegetative shoot growth emanating from the ca. 20 cm-long shoots used to assess fruit set was measured in winter. The ratio of one-year-old shoot growth to total shoot length was determined as indication of vegetative growth.

Return bloom.

Trees were scored visually at full bloom (FB) (27 October 2008), from 0 to 5, where 0 represents zero flowers and 5 represents a very heavy bloom. Selective harvesting according to size occurred on 11 and 30 March, while remaining fruit were picked on 31 March 2009. The yield per tree was assessed at each harvest date and used to calculate yield in ton ha^{-1} for each treatment. Cumulative yield was calculated over the two seasons. Fruit size was assessed on a random sample of 10 fruit per tree collected at each harvest date.

Statistical analysis.

Data were analysed with the General Linear Models (GLM) procedure of the SAS (Statistical Analysis System) computer program (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC., USA). Orthogonal linear and quadratic contrasts for NAA concentration as well as a contrast for comparison of NAA with the control were included in the analysis.

Results

2007/2008

Fruit set: Fruit set seemed to decrease linearly with an increase in NAA concentration ($p = 0.0521$) and NAA at 200 mg L^{-1} seemed to decrease fruit set compared to the control ($p = 0.0562$) (Table 1).

Harvest distribution: NAA had no effect on the harvest distribution (Figure 1).

Yield: NAA application decreased the number of fruit per tree by 19.1% on average compared to the control (Table 1), but there was no significant difference between the NAA treatments. In terms of yield, no significant treatment effect was obtained, however NAA applications significantly ($p = 0.0305$) decreased yield on average (12 %) compared to the control (Figure 2).

Fruit quality: NAA had no effect on the average fruit size of the first harvest. However, NAA significantly increased the average fruit weight (Figure 3) and diameter (Figure 4) of the second harvest and for the entire crop. Fruit weight and fruit diameter of the second harvest increased linearly with an increase in NAA concentration. Although the pip to fruit ratio over the entire crop was unaffected by NAA treatment, NAA at 200 mg L^{-1} decreased the pip to fruit ratio of the second harvest compared to the untreated control (Table 2).

Yield per category: Despite no significant treatment differences, NAA on average increased the yield of jumbo and decreased the yield of oil olives compared to the control (Figure 5). All three NAA concentrations decreased the yield of medium olives compared to the control while NAA at 150 and 200 mg L^{-1} decreased the yield of large olives compared to the control.

All three NAA concentrations significantly increased the percentage of the crop in the jumbo category (%) while the percentage of fruit in the jumbo category also increased linearly with NAA concentration (Figure 6). No treatment effect was obtained in the large category. Although NAA application decreased the percentage fruit in the small and medium (only 150 and 200 mg L^{-1}) categories compared to the control, the percentage fruit in these categories was generally quite small.

Income per category: There was no difference in table olive income or total income per ha between treatments (Figure 7). Even though NAA on average decreased the income for oil olives compared to the control, the contribution of oil olives to the total income per ha was negligible.

Vegetative growth: NAA treatment did not affect vegetative growth (Table 1).

Return bloom and yield in 2008/2009: NAA had no effect on the extent of the return bloom, which was equally poor for all treatments (Table 1). NAA also had no significant effect on yield, which was, on average, ca. 40% less compared to the previous season (Figure 2). NAA had no effect on harvest distribution (Figure 8) or fruit size (Figures 9 and 10).

Discussion

The decision on when to begin harvesting 'Barouni' olives depends on fruit size. 'Barouni' olives are grown for table purposes only, as the amount of oil accumulated in fruit is low. Fruit not qualifying for table usage are worth less than a fifth compared to table fruit and less than a third compared to fruit of oil cultivars (Scrimgeour, personal communication 2010). Olive oil farmers measure their production efficiency in oil weight produced per ha and not in fruit weight per ha. It is therefore very important to keep in mind that as many as possible 'Barouni' fruit should qualify for table usage to optimise the value of the crop.

On average, NAA application in 2007/2008 decreased fruit set by 12% ($p = 0.0557$) and estimated fruit number per tree by 19% (0.0021) compared to the control. The decrease in fruit number was offset by an increase in fruit size, resulting in a decrease in yield of only 9.9% ($p = 0.0305$). Although fruit set seemed to decrease linearly ($p = 0.0521$) with an increase in NAA concentration, there was no concentration effect on fruit number or yield per tree. NAA application had no effect on fruit size at the first harvest, which was expected considering that big fruit are selectively picked at the first harvest. The thinning effect of NAA on fruit size was not sufficient to increase the proportion of the crop removed at the first harvest. All NAA applications increased fruit size of the second harvest compared to the control and fruit size increased linearly with an increase in NAA concentration. The effect of NAA concentration on fruit size may also relate to the apparent linear decrease in fruit set with an increase in NAA concentration ($p = 0.0521$).

Although treatments did not differ significantly ($p = 0.1047$), NAA increased jumbo fruit yield by 21.2 % on average compared to the control ($p = 0.0446$) (Figure 5). Yield per fruit size category was of lesser importance in the 2007/2008 season since fruit from all categories qualifying for table olive use (medium, large and jumbo) had the same value (R8.80 per kg). However, if premium prices were to be paid for jumbo fruit, NAA application may increase income per kg fruit produced by increasing the proportion of fruit in this category. In similar research on 'Manzanillo', the income per ton increased with the increase in NAA concentration, when premium prices were paid for larger fruit (Krueger et al, 2002).

The return bloom in 2008/2009 was exceptionally poor resulting in ca. 40% lower yield than in the previous season. No treatment differences in bloom, yield or fruit quality were

found and this may have been due to the NAA treatment not causing a sufficient decrease in fruit numbers in the previous season. Stutte and Martin (1986) found that the number of seeds present on olive trees correlates negatively with the extent of flower initiation. Even though the highest NAA concentration of 200 mg L^{-1} decreased yield by 15.7% to 17 ton ha^{-1} in 2007/2008, this is still a much higher yield compared to an average season (ca. 12 ton ha^{-1}) (Scrimgeour, 2010 & Krueger, personal communication 2011). The effect of NAA on fruit number was also not of sufficient extent to increase vegetative growth and thereby create more potential bearing sites for the next season. A heavy crop load is a very strong carbohydrate sink that receives resources at the expense of shoot growth (Dag et al., 2009; Lavee, 2006). Our intention was to repeat the experiment in the 2008/2009 season with a highest NAA concentration of 400 mg L^{-1} to determine whether a stronger thinning effect and therefore increased return bloom could be attained. However, the orchard where the NAA was applied had a very poor fruit set and the experiment had to be discarded.

Recent work on 'Barnea' olives showed that higher NAA concentrations than the standard application rate of 150 mg L^{-1} could be more beneficial in breaking the alternate bearing cycle (Dag et al., 2009). NAA at 320 mg L^{-1} induced relatively constant yield in the year of application and in the subsequent year. Krueger et al. (2002) found that highest return bloom was obtained with 450 and 600 mg L^{-1} concentrations. When harvesting costs were subtracted from income per hectare, the return was highest with 450 mg L^{-1} application. However, Dag et al. (2009) cautioned that the potential impact of excessive thinning should be carefully considered before deciding on higher application rates.

Conclusion

NAA application up to 200 mg L^{-1} had a mild thinning effect in 'Barouni' olive. Although the thinning effect was not sufficient to reduce yield alternation, fruit size was increased. This increase in fruit size may increase income in the event that a premium is paid for larger fruit. Further research is needed to assess the effect of higher NAA concentrations on fruit quality and alternation in 'Barouni'. Since application of NAA 10 DAFB instead of 15 DAFB seems to thin more aggressively (Dag et al., 2009), investigating earlier application might also prove worthwhile.

Literature cited

Baktir, I., Ulger, S. & Himelrick, D.G., 2004. Relationship of seasonal changes in endogenous plant hormones and alternate bearing of olive trees. HortSci. 39: 987-990.

Dag, A., Bustan, A., Avni, A., Lavee, S. and Riov, J., 2009. Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees. Crop Pasture Sci. 60: 1124 - 1130.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Fernández-Escobar, R., Benlloch, M., Navarro, C. & Martin, G.C., 1992. The time of floral induction in olive. J. Am. Soc. Hort. Sci. 117: 304-307.

Harley, C.P., Moon, H.H. & Regeimbal, L.O., 1958. Evidence that post-bloom apple-thinning sprays of naphthalene acetic acid increase blossom-bud formation. Proc. Amer. Soc. Hort. Sci. 72: 52-56.

Harley, C.P. & Regeimbal, L.O., 1959. Comparative effectiveness of naphthalene acetic acid and naphthylacetamide sprays for fruit thinning York Imperial apples and initiating blossom buds on Delicious apple trees. Proc. Amer. Soc. Hort. Sci. 74: 64-66.

Hartmann, H.T., 1951. Time of floral differentiation of the olive in California. Bot. Gaz. 112: 323-327.

Hartmann, H.T., 1952. Spray thinning of olives with Naphthalene acetic acid. Proc. Amer. Soc. Hort. Sci. 59: 187-195.

Krueger, W. H., Heath, Z. R. & Mulqueeny, B., 2002. Effect of spray solution concentration, active ingredient, certain additives and sequential treatments of naphthalene acetic acid for chemical thinning of Manzanillo table olives. Acta Hort. 586: 267-271.

Krueger, W.H., Maranto, J. & Sibbett, G.S., 2004. Olive fruit thinning. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Ed.) Pp. 101-104. University of California, Oakland, California, USA.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Lavee, S., 2006. Biennial bearing in olive (*Olea europaea L.*). FAO Network. Olea 25: 5-12. July 2006.

Link, H., 2000. Significance of flower and fruit thinning on fruit quality. Plant Growth Regul. 31:17-26.

Martin, G.C., Connell, J.H., Freeman, M.W., Krueger, W.H. & Sibbett, G.S., 1994. Efficacy of foliar application of two naphthaleneacetic acid salts for olive fruit thinning. Acta Hort. 356: 302-305.

Martin, G.C., Lavee, S., Sibbett, G. S., Nishijima, S. & Carlson, S. P., 1980. A new approach to thinning olives. Calif. Agric. 34: 7-8.

Monselise, S.P. & Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. Hort. Rev. 4: 128-173.

Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., & Meier, U., 2002. Phenological growth stages of olive trees (*Olea europaea*). Ann. Appl. Biol. 140: 151-157.

Stutte, G.W. & Martin, G.C., 1986. Effect of killing the seed on return bloom of olive. Sci Hort 29: 107-113.

Williams, K.M. & Fallahi, E., 1999. The effects of exogenous bioregulators and environment on regular cropping of apple. HortTech. 9(3): 323-327.

Table 1: The effect of NAA application in 2007/2008 on fruit set percentage, number of 'Barouni' fruit harvested and vegetative growth during the year of application and on return bloom in the 2008/2009 season. Means were separated by LSD (5%).

Treatment	Fruit set %	Estimated number of fruit	Vegetative ratio [R]	Return bloom[Z]
Control	48.7 a [y]	12000 a	0.38 NS	1.1 NS
NAA 100 mg·L^{-1}	47.1 ab	9959 b	0.36	1.5
NAA 150 mg·L^{-1}	41.5 ab	10004 b	0.22	1.1
NAA 200 mg·L^{-1}	39.7 b	9166 b	0.30	1.4
Pr > F				
Treatment	0.0562	0.0132	0.1423	0.2283
NAA vs Control	0.0557	0.0021	0.1626	0.2096
NAA Lin	0.0521	0.3440	0.4061	0.6041
NAA Quad	0.5259	0.5408	0.0879	0.1135

[y] *means with different letters differ significantly at p<0.05*

[NS] *no significant differences between treatments*

[R] *One year old shoot length divided by one and two year old shoot length*

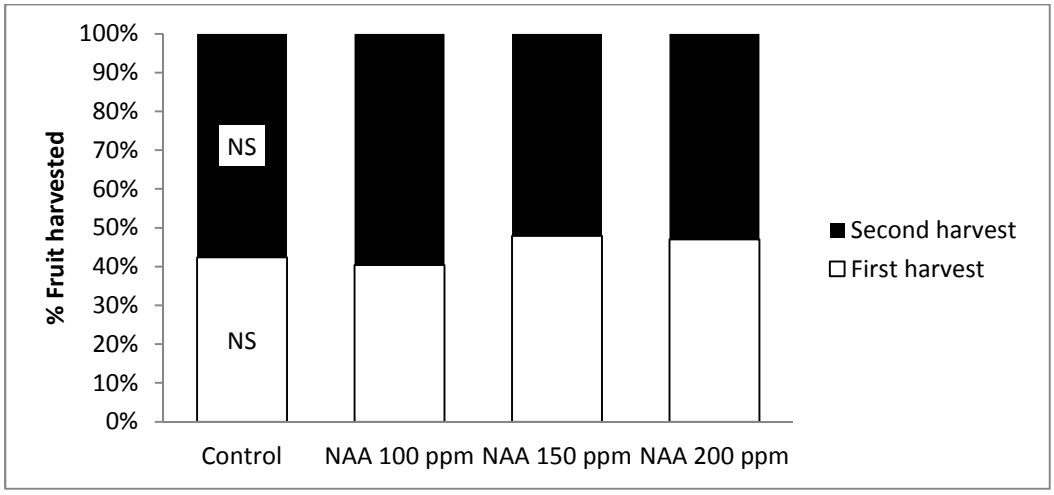
[z] *Score out of 5 where 0 represents zero flowers and 5 represents a very heavy bloom*

Table 2: The effect of NAA application in 2007/2008 on the pip to fruit diameter ratio of 'Barouni' olives. Means were separated by LSD (5%).

Treatment	First harvest	Second harvest	Average of season
Control	0.492 NS	0.486 a [w]	0.490 NS
NAA 100 mg·L^{-1}	0.486	0.478 ab	0.482
NAA 150 mg·L^{-1}	0.445	0.483 a	0.455
NAA 200 mg·L^{-1}	0.498	0.473 b	0.485
Pr > F			
Treatment	0.3936	0.0378	0.4813
NAA vs Control	0.5710	0.0388	0.4208
NAA Lin	0.7253	0.2922	0.9305
NAA Quad	0.1155	0.0607	0.1840

[NS] *no significant differences between treatments*

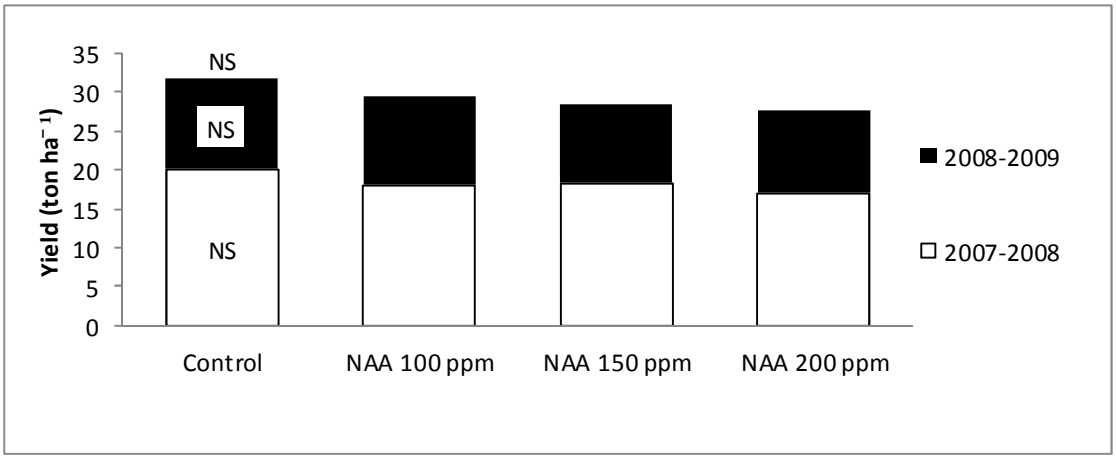
[w] *means with different letters differ significantly at p<0.05*



Pr > F	First harvest	Second harvest
Treatment	*0.3784*	*0.3784*
NAA vs Control	*0.5099*	*0.5099*
NAA Lin	*0.1875*	*0.1875*
NAA Quad	*0.3423*	*0.3426*

NS no significant differences between treatments

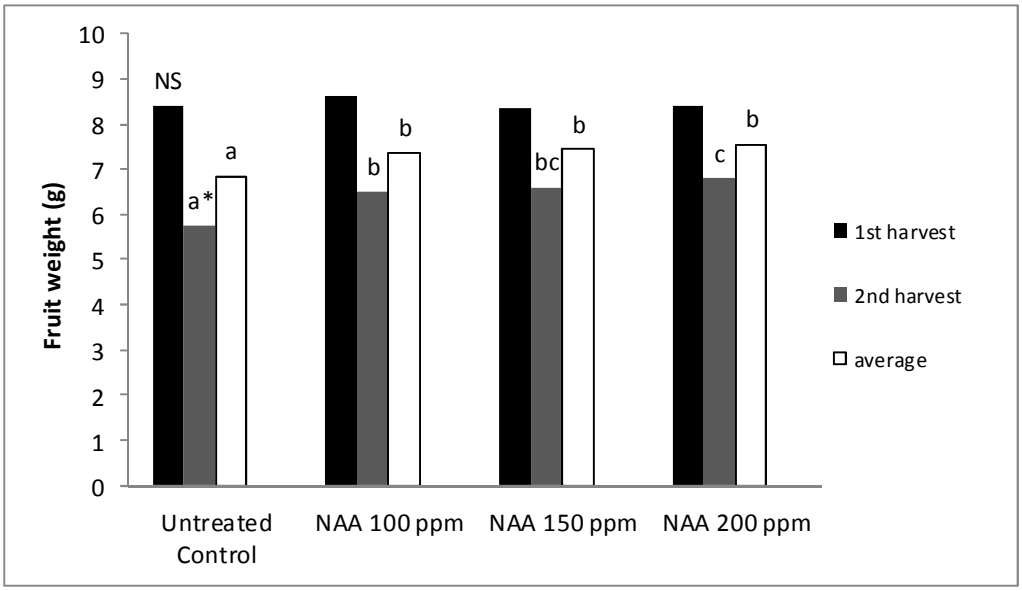
Figure 1: The effect of NAA application in 2007on harvest distribution of 'Barouni' olives in the season of application. The first selective harvest according to fruit size was done on 6 March 2008 and all remaining fruit were harvested on 24 March 2008.



Pr > F	2007/2008	2008/2009	Cumulative
Treatment	*0.1202*	*0.8041*	*0.1272*
NAA vs Control	*0.0305*	*0.5765*	*0.0330*
NAA Lin	*0.4245*	*0.6329*	*0.2913*
NAA Quad	*0.4823*	*0.5150*	*0.9024*

[NS] *no significant differences between treatments*

Figure 2: The effect of NAA application in 2007/2008 on yield of 'Barouni' olives in the season of application, the subsequent season and cumulatively over the two seasons.

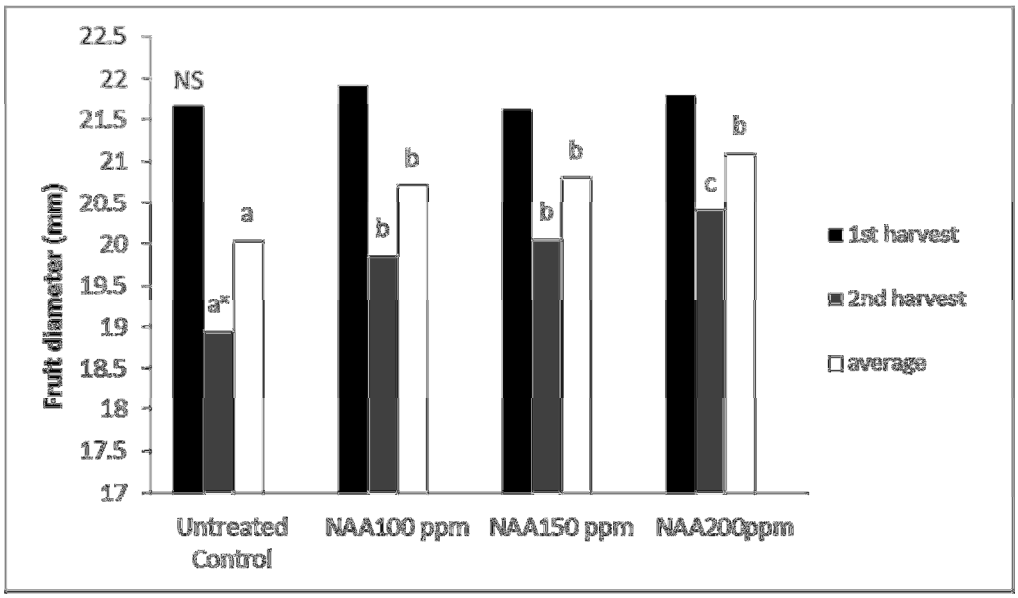


Pr > F	First harvest	Second harvest	Average of season
Treatment	*0.8499*	*<0.0001*	*0.0073*
NAA vs Control	*0.8335*	*<0.0001*	*0.0009*
NAA Lin	*0.5084*	*0.0470*	*0.3368*
NAA Quad	*0.5877*	*0.6827*	*0.8859*

NS no significant differences between treatments

** means within a harvest date with different letters differ significantly at p<0.05*

Figure 3: The effect of NAA application in 2007 on fruit weight of 'Barouni' olives in the season of application. The first selective harvest according to fruit size was on 6 March 2008 and the second harvest of remaining fruit on 24 March 2008.

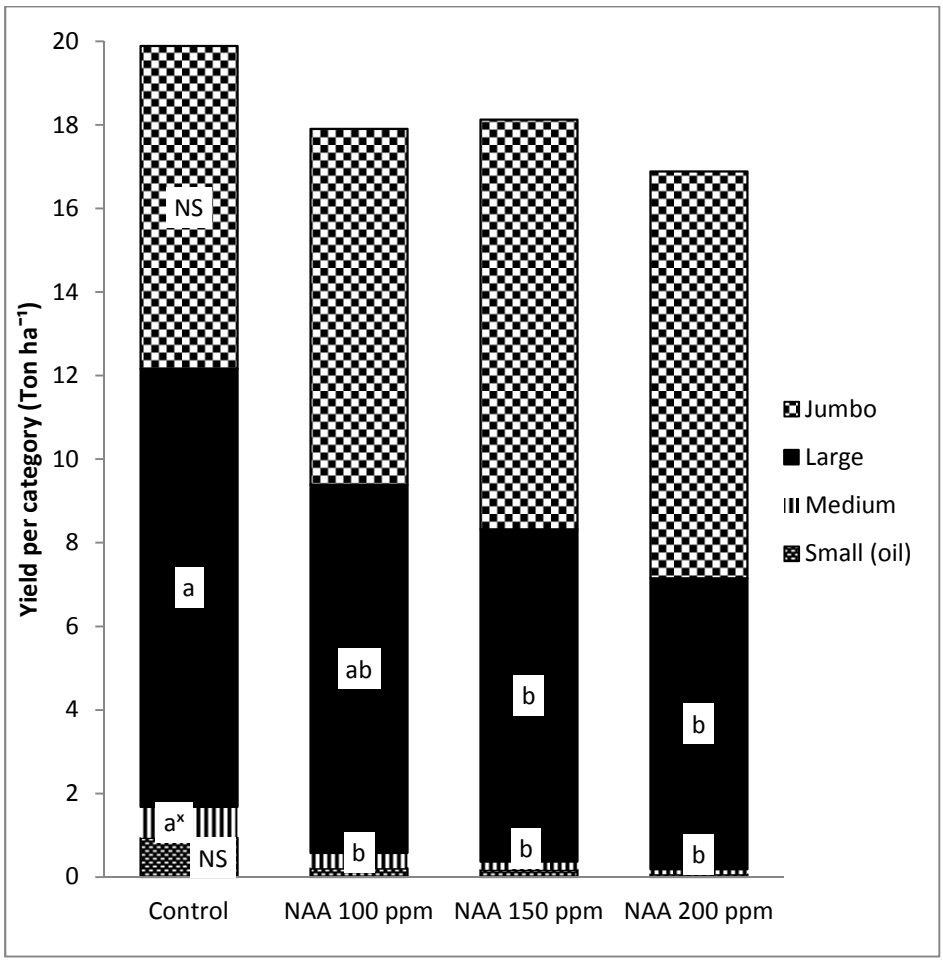


Pr > F	First harvest	Second harvest	Average of season
Treatment	*0.7545*	*<0.0001*	*0.0001*
NAA vs Control	*0.6218*	*<0.0001*	*<0.0001*
NAA Lin	*0.7229*	*0.0012*	*0.0636*
NAA Quad	*0.3729*	*0.5363*	*0.6123*

[NS] *no significant differences between treatments*

[x] *means with different letters differ significantly at p<0.05*

Figure 4: The effect of NAA application in 2007 on fruit diameter of 'Barouni' olives in the season of application. The first selective harvest according to fruit size was on 6 March 2008 and the second harvest of remaining fruit on 24 March 2008.

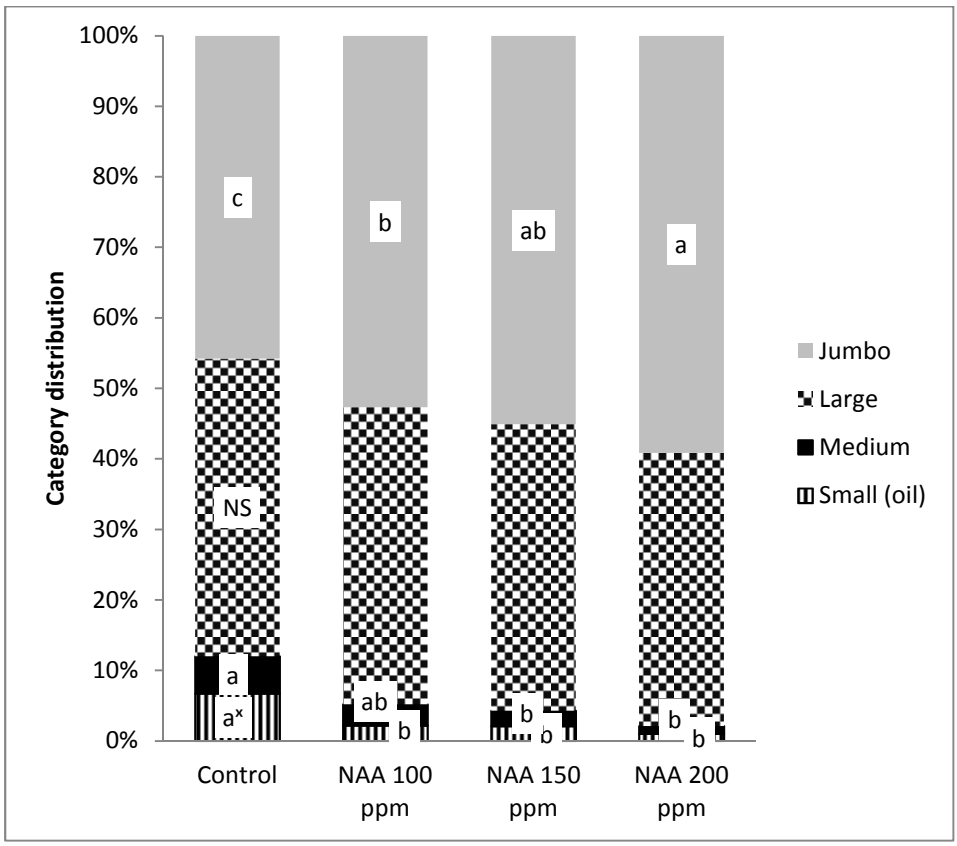


Pr > F	Small (< 4 g)	Medium (4 – 4.55 g)	Large (4.55 – 5.4 g)	Jumbo (>5.4 g)
Treatment	*0.0721*	*0.0032*	*0.0315*	*0.1047*
NAA vs Control	*0.0101*	*0.0006*	*0.0102*	*0.0446*
NAA Lin	*0.6931*	*0.1271*	*0.1182*	*0.2105*
NAA Quad	*0.9119*	*0.7788*	*0.9507*	*0.4162*

NS no significant differences between treatments

x means within a fruit size category with different letters differ significantly at p<0.05

Figure 5: The effect of NAA application in 2007/2008 on yield per category of 'Barouni' olives in the season of application.

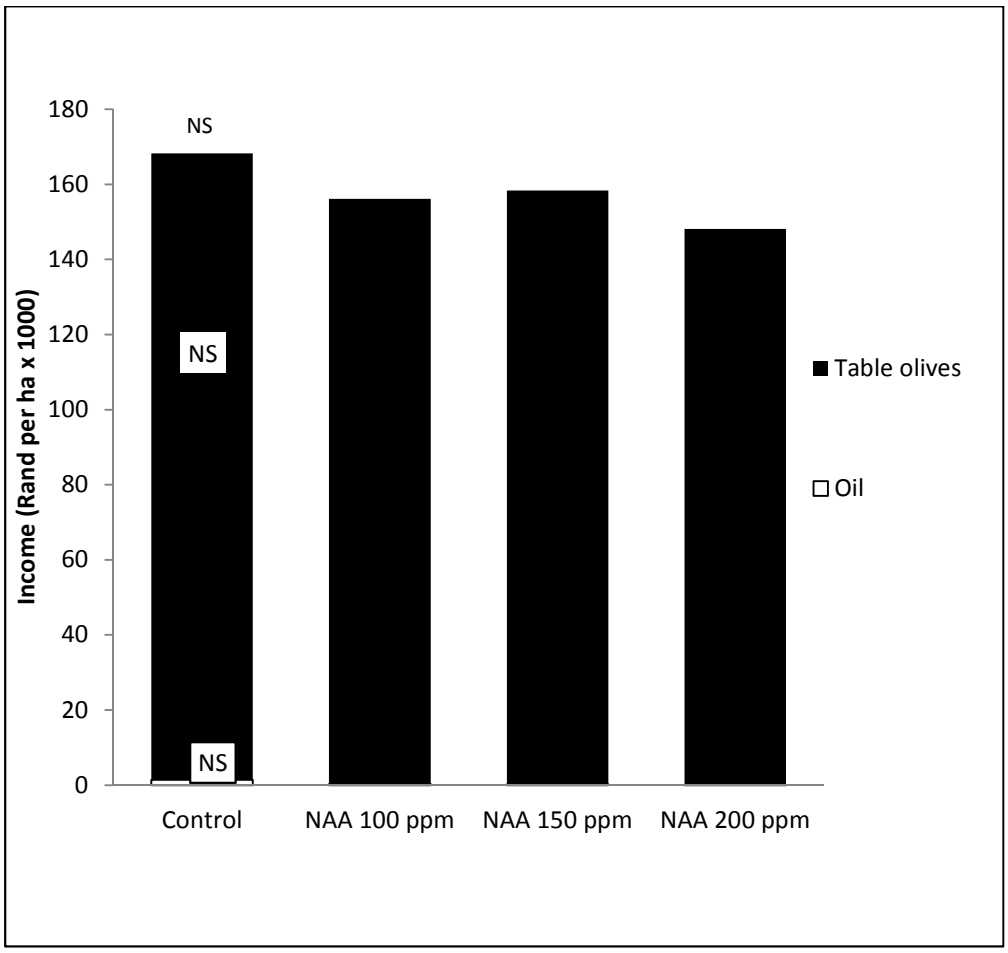


Pr > F	Small (< 4 g)	Medium (4 – 4.55 g)	Large (4.55 – 5.4 g)	Jumbo (>5.4 g)
Treatment	*0.0478*	*0.0113*	*0.7434*	*0.0002*
NAA vs Control	*0.0067*	*0.0028*	*0.5654*	*<0.0001*
NAA Lin	*0.5791*	*0.1230*	*0.3503*	*0.0203*
NAA Quad	*0.7820*	*0.9084*	*0.9535*	*0.7214*

NS no significant differences between treatments

x means within a fruit size category with different letters differ significantly at p<0.05

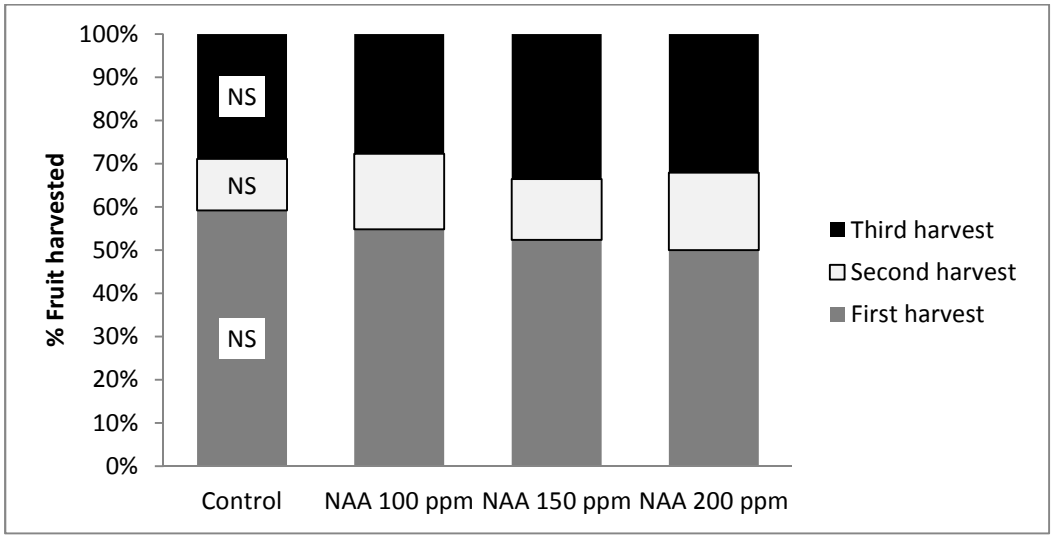
Figure 6. The effect of NAA application in 2007/2008 on category distribution of 'Barouni' olives in the season of application.



Pr > F	Table olives	Oil olives	Total Income
Treatment	*0.4721*	*0.0722*	*0.4047*
NAA vs Control	*0.1922*	*0.0101*	*0.1518*
NAA Lin	*0.5156*	*0.6934*	*0.5002*
NAA Quad	*0.5500*	*0.9126*	*0.5428*

NS no significant differences between treatments

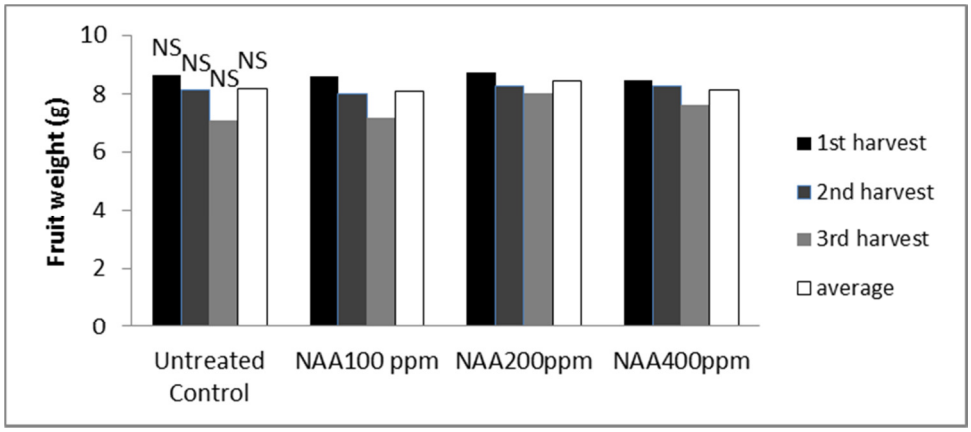
Figure 7: The effect of NAA application in 2007/2008 on income per ha of 'Barouni' olives in the season of application.



Pr > F	First harvest	Second harvest	Third harvest
Treatment	*0.2601*	*0.4049*	*0.4306*
NAA vs Control	*0.0670*	*0.2616*	*0.1983*
NAA Lin	*0.4686*	*0.9629*	*0.4312*
NAA Quad	*0.8081*	*0.2027*	*0.4983*

[NS] *no significant differences between treatments*

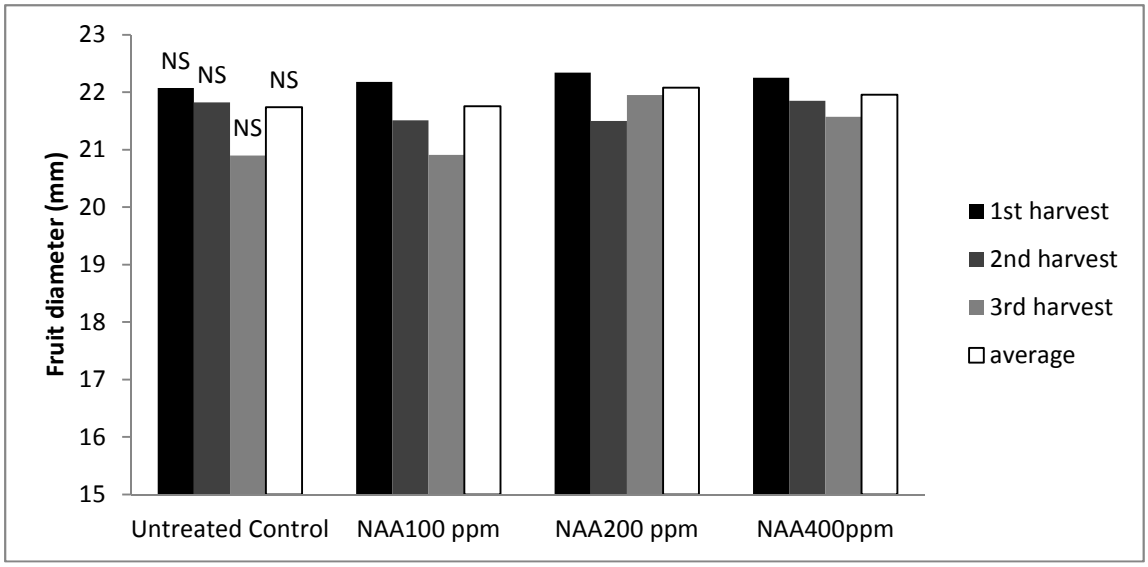
Figure 8: The effect of NAA application in 2007/2008 on the harvest distribution of 'Barouni' olives in 2008/2009. Selective harvesting according to size and colour (only green) occurred on 11 and 30 March, while all remaining fruit were strip picked on 31 March 2009.



Pr > F	First harvest	Second harvest	Third harvest	Average of season
Treatment	*0.8948*	*0.8589*	*0.0967*	*0.6889*
NAA vs Control	*0.8657*	*0.8585*	*0.1286*	*0.9246*
NAA Lin	*0.7056*	*0.4575*	*0.2405*	*0.8591*
NAA Quad	*0.5186*	*0.6954*	*0.0900*	*0.2400*

[NS] *no significant differences between treatments*

Figure 9: The effect of NAA application in the 2007/2008 season on fruit weight of 'Barouni' olives in 2008/2009. Selective harvesting according to size occurred on 11 and 30 March, while remaining fruit were picked on 31 March 2009.



Pr > F	First harvest	Second harvest	Third harvest	Average of season
Treatment	*0.8898*	*0.6164*	*0.0696*	*0.7253*
NAA vs Control	*0.5170*	*0.4922*	*0.1265*	*0.5108*
NAA Lin	*0.8399*	*0.3336*	*0.1549*	*0.5709*
NAA Quad	*0.6998*	*0.5501*	*0.0805*	*0.4645*

NS no significant differences between treatments

Figure 10: The effect of NAA application in the 2007/2008 season on fruit diameter of 'Barouni' olives in the 2008/2009 season. Selective harvesting according to size occurred on 11 and 30 March, while remaining fruit were picked on 31 March 2009.

Paper 2. Evaluate the use of NAA to thin 'Mission' olives in the "on'' year to increase fruit quality and to decrease alternate bearing under South African conditions.

Abstract. Alternate bearing is a widespread phenomenon in many fruit trees and a major problem facing olive growers. A high crop load in the current "on" season negatively affects flower initiation and lowers the return bloom in the subsequent "off" season. Fruit thinning early in an "on" season with naphthalene acetic acid (NAA) is widely used in various olive growing countries to decrease fruit numbers and increase fruit size during the same season, and to increase fruit numbers in the subsequent "off" season. The efficacy of NAA has not been tested under South African conditions and also not for Mission, the major cultivar in South Africa. 'Mission' olives are of dual purpose, as they are used as table (only black fruit) and oil olives (black fruit not qualifying for table usage and all remaining green fruit). Payments for table olives increase with fruit size, whereas the price for oil olives is not dependent on fruit size and is much lower than for table olives. In the current study, NAA was applied at 100 to 400 mg L^{-1} to determine the optimum concentration under South African conditions. In the 2008/2009 season, NAA significantly decreased the total fruit number by 46% and yield by 32%. Fruit diameter and weight increased by 9% and 22% respectively. Although NAA application on average decreased yield by 32% compared to the untreated control, the gross income was not reduced due to the increase in fruit quality. The high crop load of the untreated control produced high volumes of green fruit only suitable for oil, irrespective of fruit size. The results indicate that fruit thinning with NAA may improve table olive quality under South African conditions. However, the effect of NAA on yield alternation could not be assessed as return bloom (2009/2010) for 'Mission' was very poor throughout South Africa. Effective NAA concentrations for optimal thinning under South African conditions appear to be slightly higher compared to optimal concentrations (150 mg L^{-1}) used in California. On the other hand, application at 400 mg L^{-1} seemed to decrease vegetative growth, which may decrease bearing positions in the subsequent season. According to work done in Israel, earlier application on NAA has a more aggressive thinning action and should be considered for South African conditions to offset the cost of NAA application.

Introduction

The olive is one of the extreme alternate bearers (Krueger et al., 2004; Lavee, 1996). The yield of biannual bearing cycles may range from 0 ton ha^{-1} in "off" seasons to 30 ton ha^{-1} in "on" season (Lavee, 2006). Alternate bearing causes substantial fluctuation in income for olive farmers, as the heavy crop loads of "on" season give rise to very poor fruit quality (i.e., small fruit size in several oil (Dag et al., 2009) and table olive cultivars (Hartmann, 1952; Krueger et al., 2004; Martin et al., 1980). Fruit size is the limiting factor, as too small fruit do not qualify as table olives (Lavee, 2006), thus resulting in a significant loss of income, whereas the increase of fruit size in an "off'' year does not make up for the loss in yield (Krueger et al., 2002). That said, not only does alternate bearing create challenges regarding operating and utilizing storage and processing facilities, but also with the planning of labour and other horticultural farming practices (Monselise and Goldschmidt, 1982).

The degree of flower initiation for the subsequent season correlates negatively with the number of fruit of the current crop (Stutte and Martin, 1986). Developing seeds produce high levels of gibberellic acids (GAs) that have direct adverse effects on flower initiation (Lavee, 1996; Fabbri and Benelli, 2000). The high crop load of an "on" season is also a strong carbohydrate sink that receives resources at the expense of shoot growth (Lavee, 1996). Since flowers form on one-year-old shoots, a decrease in vegetative growth in the "on" season may furthermore contribute to a low crop in the next season (Krueger et al., 2004). Hence, a heavy crop load may decrease both flower initiation and fruiting positions for the following season.

Excessive crops must be reduced early in the "on" season to overcome biennial bearing and to obtain adequate fruit quality. According to Williams and Fallahi (1999), fruit removal after flower initiation only has an effect on crop load. Olive flower induction occurs as early as 7 to 8 weeks after full bloom (FB) at roughly the same time of endocarp sclerification (pit hardening) of the current season's fruit (Baktir et al., 2004; Fernández-Escobar et al., 1992; Sanz-Cortés et al., 2002). In recent work (Andreini et al., 2008), it was possible to distinguish between "on'' and "off" season axillary buds by late summer, close to pit hardening.

Fruit thinning can rectify or ameliorate an established alternate bearing cycle and is also a management technique used to increase fruit size (Link, 2000). Fruit thinning between 10 and 20 days after full bloom (DAFB) was found to increase vegetative growth, flower abundance, fruit size and cumulative yield (over two seasons) in olive (Dag et al., 2009; Krueger et al., 2002; Lavee, 2006; Martin et. al., 1994). Since chemical thinning increases the leaf to fruit ratio, it is much more effective than pruning, which maintains this ratio (Krueger et al., 2004).

In California, the synthetic auxin, naphthalene acetic acid (NAA), has been used for olive thinning since the 1950's (Hartmann, 1952). NAA application at 150 mg L^{-1} roughly 15 DAFB effectively thins and decreases alternate bearing and also increases return bloom in various oil (Dag et al., 2009) and table (Hartmann, 1952; Krueger et al., 2004; Martin et al., 1980) olive cultivars. An increase in fruit quality, i.e., fruit size, flesh-to-pit ratio and oil content was furthermore noted (Martin et al., 1980). NAA application may also have a direct stimulating effect on flower initiation independent of its thinning effect (Harley et al., 1958).

Due to increasing competition in the South African and international trading market and escalating operational costs, olive producers can no longer ignore the negative effects of yield alternation. South African olive producers have up to now endured the negative effects of alternate bearing and not made use of chemical fruit thinning. Since the effectiveness of NAA is influenced by climatic conditions (Hartmann, 1951) and also depends on genotype (Krueger et al., 2004), the work reported here was initiated to evaluate the use of NAA and establish optimum concentrations for 'Mission' olive under South African conditions.

Materials and Methods

Experiments were conducted in the 2007/2008 and 2008/2009 seasons at Buffet Olives in Paarl (Latitude 33°45'S, Longitude 18°56'E) in the Mediterranean-type climate Western Cape Province of South Africa.

Experiment 1

2007/08

NAA (Planofix, Bayer CropScience AG, Isando, South Africa) was applied at 100, 150 and 200 mg L^{-1} 15 days after full bloom (DAFB) on 19 November 2007 at an average fruit size of 3.2 mm in an orchard planted in 1982 at a spacing of 9 x 4.5 m. Trees have an average canopy volume of 40 m^3.

Treatments, including an untreated control, were randomized in 7 blocks with two trees per plot and guard trees between plots. NAA was applied early on wind still mornings with a truck-mounted motorized sprayer until drip off. Each tree received ca. 6 L of the spray mixture. No wetting agent was used as per Bayer Crop Science recommendation.

Fruit set.

Three one-year-old shoots of about 20 cm long (ca.15 fruit per shoot) per tree were selected and the number of fruit per shoot counted on the day of NAA application (19 November 2007). Fruit were counted again on 18 January 2008 after the fruit drop period and fruit set was calculated.

Yield, fruit quality and return bloom.

Each treatment was harvested twice. Only fruit that were black and exceeded a minimum weight of approximately 4 g were picked during the first selective harvest on 8 May. Fruit colour was taken into account by harvesting green, half-ripe and black fruit separately. Total yield and overall fruit quality could not be assessed due to a storm after the first harvest that blew most of the remaining fruit off the trees. Return bloom was not assessed since comparison with total yield would not be possible. The experiment was subsequently discarded.

2008/09

Treatments.

NAA was applied at 100, 200 and 400 mg L^{-1} 15 DAFB on 20 November 2008 at an average fruit size of 3.0 mm in an orchard planted in 1993 at a spacing of 7 x 4.5 m. Trees have an average canopy volume of 40 m^3.

Application occurred in the same manner than in the previous season. Treatments, including an untreated control, were randomized in 9 blocks with two trees per plot and guard trees between plots.

Measurements.

Fruit set was determined as in 2007/2008.

Harvest occurred on 5 May, 8 and 11 June 2009. Each treatment was harvested three times. Only fruit that were black and exceeded a minimum weight of approximately 4 g were picked during the first two selective harvests. All remaining fruit, which was green in colour, were picked on 11 June 2009. Fruit colour was taken into account by differentiating only between green and black fruit. The fruit of each tree were weighed to determine yield in kg per tree, subsequently converted to ton ha^{-1}. A 20-fruit sample per treatment plot was randomly collected on each harvest date to determine average fruit and pip diameter (measured by electronic calliper), the pip-to-flesh ratio, average fruit mass and the percentage black and green fruit. Fruit number per tree was estimated by dividing the total fruit mass per tree by the average fruit mass of the 20-fruit sample.

Trees were scored visually at FB (26 October 2009), from 0 to 5, where 0 represent zero flowers and 5 represents a very heavy bloom.

Economic analysis.

'Mission' olives are divided into four size categories according to South African industry size standards, viz. large (>4.55 g), medium (4 – 4.55 g), standard (3.3 – 4 g) and oil (<3.3 g). To determine the percentage of the crop per size category according to fruit weight, the average fruit diameters and average fruit weights of treatment replications were plotted and a linear regression line fitted to the data. Individual fruit weights of the 20 fruit per treatment replicate were determined by inserting fruit diameters into the equation obtained from the regression line. Prices varied between categories, viz. R2.90/kg for green and small black fruit (<3.3 g), R5.50/kg for standard, R9.85/kg for medium and R11/kg for large fruit (Scrimgeour, personal communication 2010). Yield per category, income per category and

category distribution were determined. Income per ha was determined for each treatment by adding the incomes per category.

Vegetative growth.

All new vegetative shoot growth emanating from the ca. 20 cm-long shoots used to assess fruit set was measured in winter. The ratio of one-year-old shoot growth to total shoot length was determined.

Experiment 2

To establish the optimum crop load in 'Mission' that will maximise income, branches were thinned by hand after fruit drop ~5 weeks after full bloom (WAFB) on 9 December 2008 at a fruit size of ~5-6 mm. The untreated control received no thinning while other treatments were thinned by 10, 25, 50 and 75 %. Treatments were randomized in seven blocks with two branches per plot. Branches with an average total shoot length of 150 cm were used. The measured shoot length included two-year-old wood, but this was a small percentage of total shoot length. The orchard used was planted in 1993 at a spacing of 7 x 4.5 m.

Fruit quality at harvest.

All fruit were harvested on 4 May 2009. Fruit number, average fruit weight, fruit and pip diameter (measured by electronic calliper), the pip-to-flesh ratio and the fruit number at harvest as a percentage of the number of fruit at the onset of the experiment were determined.

Vegetative growth.

Vegetative growth was measured during winter (28 August 2009) on the same branches used for the fruit thinning treatments. The ratio of one-year-old shoot growth to total shoot length was determined.

Return bloom.

Branches were scored visually at FB (2 November 2009), from 0 to 5, where 0 represent zero flowers and 5 represents a very heavy bloom.

Statistical analysis.

Data were analysed with the General Linear Models (GLM) procedure of the SAS (Statistical Analysis System) computer program (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC., USA). Orthogonal linear and quadratic contrasts for NAA concentration as well as a contrast for comparison of NAA with the control were included in the analysis.

Results

Experiment 1

2007/2008

Fruit set: The highest NAA concentration (200 mg L^{-1}) significantly decreased fruit set (17.3%) compared to the untreated control (Table 1).

Yield and fruit quality: NAA had no significant effect on fruit quality at the first harvest (data not presented). Total yield and overall fruit quality could not be assessed due to a severe storm after the first harvest that removed most of the remaining fruit from the trees. This experiment was subsequently discarded.

2008/2009

Fruit set: All NAA treatments were equally effective in thinning fruit (Table 1). Final fruit set (fruit remaining on tagged shoots after fruit drop compared to the number of fruit at the onset of the experiment) for NAA was 11.8% compared to 53% for the untreated control.

Harvest distribution: The percentage of the crop harvested on the first harvest date increased linearly while the percentage of the crop harvested on the third (last) harvest date decreased linearly with an increase in NAA concentration (Figure 1). Although treatment differences were not significant for the second harvest date ($p = 0.0930$), a higher percentage of the crop were harvested from NAA treatments compared to the control ($p = 0.0241$). Of the 18 trees used for each treatment, 5 and 11 trees for NAA application at 200 and 400 mg L^{-1}, respectively, did not require a third harvest.

Yield: Both the number of fruit per tree (Table 2) and total yield (Figure 2) decreased linearly with an increase in NAA concentration. NAA significantly decreased fruit per tree and total yield compared to the control. NAA treatment increased the yield of black fruit by 47% compared to the control (Figure 2). No differences were found between NAA concentrations. Yield of green fruit decreased linearly with an increase in NAA concentration and all the NAA concentrations decreased the yield of green fruit compared to the control. NAA application significantly increased the percentage of the crop comprising of black fruit compared to the control and the percentage black fruit increased linearly with increasing NAA concentration (Figure 3).

Fruit quality: NAA treatment significantly increased average fruit weight and diameter of black and all fruit compared to the control (Figure 4 and 5). Except for black fruit where the trend was nearly significant ($p = 0.0604$), average fruit weight and diameter increased linearly with NAA concentration. NAA concentration seemed to have a lesser effect on fruit size compared to NAA application *per se*. While the pip to flesh ratio for black fruit was unaffected by NAA treatment, the average ratio of all fruit showed a significant linear decrease with an increase in NAA concentration for green fruit as well as for the entire crop (Table 3). NAA at 200 and 400 mg L^{-1} decreased the ratio compared to the control.

Yield per category: Most fruit fell in the large and oil categories (Figure 6 and 7). All NAA treatments significantly increased the yield of large fruit and decreased oil olives compared to the control (Figure 6). The yield of oil olives decreased linearly with an increase in NAA concentration. Despite no significant treatment differences, NAA on average seemed to decrease the yield of standard and medium sized olives compared to the control.

All three NAA concentrations significantly increased the percentage of the crop in the large category while the percentage of fruit in the large category also increased linearly with NAA concentration (Figure 7). No treatment effect was obtained in the standard and medium categories. All three NAA concentrations significantly decreased the percentage of the crop qualifying for oil while the percentage of fruit in the oil category also decreased linearly with NAA concentration.

Income per category: NAA significantly increased the income for the large category and decreased the income for oil olives (Figure 8). Oil olive income also decreased linearly with an increase in NAA concentration (Figure 8). Although treatment differences were not significant (p=0.0502), NAA at 400 mg L^{-1} decreased the income for standard olives compared to the control. NAA on average also significantly decreased the income for medium olives despite the insignificance of treatment differences. There was no difference in total income per ha between treatments, although income did seem to decrease with an increase in NAA concentration.

Vegetative growth: It seems that NAA at 200 mg L^{-1} increased vegetative growth compared to other treatments (p = 0.0514) (Table 2).

Return bloom: Return bloom was basically absent for all treatments (data not presented).

Experiment 2

Thinning efficiency: Fruit number at harvest per meter shoot length decreased linearly with an increase in thinning severity (Table 4). Fruit number at harvest as percentage of the fruit number before thinning indicates that only slight natural fruit drop occurred between thinning and harvest for the control. For thinning severities ≥25%, slightly more fruit remained on the tree at harvest than aimed for.

Fruit quality: Fruit weight and diameter increased linearly with an increase in hand thinning (p = 0.0035 and 0.0024 respectively) (Table 4). However, the increase in fruit weight and diameter was only significant compared to the control at a thinning severity of ≥50%. Thinning had no effect on the pip to fruit ratio compared to the control, although the ratio decreased linearly with increased thinning.

Vegetative growth: Fruit thinning had no effect on new shoot growth (Table 4). However, new shoot growth as proportion of total shoot growth did seem to increase linearly (0.0661) with an increase in thinning severity.

Return bloom: No flowers were observed on any of the branches used in the trial (data not presented).

Discussion

On average, NAA application in 2008/2009 decreased fruit set and the estimated number of fruit at harvest by 78% and 46%, respectively, compared to the control. Fruit number decreased linearly with an increase in NAA concentration. No previous research on the effect of NAA on thinning in 'Mission' has been reported. However, Dag et al. (2009) reported a comparable thinning effect in 'Barnea' (26%) and 'Picual' (38%) after application of 120 mg L^{-1} NAA (10 DAFB).

The decrease in fruit number in response to NAA concentration was counteracted by an increase in fruit size resulting in an average yield decrease for NAA treatments of only 32% compared to the control. An increase in fruit size due to greater assimilate partitioning to individual fruits is a common response to fruit thinning in general (Link 2000). NAA also significantly increased the yield of black fruit compared to the control. Both the increase in the yield of black fruit as well as the increase in fruit size is important from a financial perspective. 'Mission' olives are grown for dual purpose and are used both as table and oil olives. For fruit of 'Mission' to qualify as table olives, they need to be black in colour and fall into the standard (3.3 - 4 g), medium (4 – 4.55 g) or large (>4.55 g) size categories. Green olives and black fruit <3.3 g in weight are used for oil. The value of 'Mission' oil olives is higher when compared to oil olives of most table olive cultivars, mainly due to relatively high oil content (Sutter, 2004), but is still only 25 to 53% of the value of table olives (Scrimgeour, personal communication 2011). Large 'Mission' olives sell at a higher price (R11/kg) than medium (R9.85/kg) and standard olives (R5.50/kg). Consequently, income for 'Mission' olives is maximised by increasing the yield of large, black olives. Due to the linear increase in the percentage of the crop in the large category with an increase in NAA concentration, NAA significantly increased average income of the large category compared to the untreated control. Although the yield of the control was much higher compared to NAA treatments, there was no difference in total income per ha between treatments due to the low value of fruit used for oil. Since the trial focussed on curbing alternate bearing, this outcome was highly favourable as the same income was generated with lower yields in the "on" season while income in the next season may be higher for treated trees.

Harvesting of 'Mission' olives in South Africa commences during May and may continue until August in orchards with a heavy "on" crop. Olive producers leave 'Mission' fruit on the

tree to maximise the yield of black fruit and also due to labour constraints. 'Mission' is the most planted olive cultivar in South Africa (60% of total area) and it is not always possible due to labour limitations to harvest fruit in time (Scrimgeour, personal communication 2012). NAA treatment increased the percentage of the crop harvested on the first harvest date (5 May 2009) compared to the control (39% vs. 11%) and the percentage of the crop harvested on the first date also increased linearly with an increase in NAA concentration. Conversely, the percentage of the crop harvested as green fruit on the last harvest date (11 June 2009) was much higher for the control compared to NAA treatments (67% vs. 31%, respectively) and decreased linearly from 44% to 17% with an increase in NAA concentration. Sibbett and Krueger (1998) found that a moderate 'Mission' crop matured earlier (earlier black colour development) than a heavy crop – unfortunately, the authors did not disclose what constituted a moderate and a heavy crop. Delayed ripening of a heavy olive crop is thought to be due to photosynthate limitations (Proietti, 2003). Apart from cost savings achieved with a more condensed harvest, fruit thinning with NAA has the added advantage of preventing losses to anthracnose infection. 'Mission' olives remaining on the tree during the cool and wet late autumn and winter in South Africa are prone to this disease and fruit losses can be substantial (personal observation).

Dag et al. (2009) found that thinning 'Picual' with NAA significantly increased return bloom and yield in the subsequent season compared to the control treatment. However, despite the significant thinning achieved with NAA application in 'Mission', no return bloom was found on either NAA-treated or untreated trees in the 2009/2010 season. Furthermore, no return bloom was found on adjacent olive orchards. This was most probably due to climatic limitations for floral formation experienced in the Western Cape during the 2008/2009 season. Climatic conditions during flower initiation and differentiation are known to have a major effect on the extent of flowering in spring (Lavee, 1996).

Even at the same concentrations, NAA was more effective with regard to thinning in 2008/2009 than in 2007/2008. The efficacy of NAA is known to depend on climatic conditions (Hartmann, 1951) and the differential thinning effect might be due to seasonal differences in climate after NAA application. Due to the greater thinning effect in 2008/2009, the effect on fruit quality seemed to have been more pronounced in 2008/2009. Of course, it

is difficult to be certain about this due to the wind storm that made assessment of overall fruit quality and yield impossible for the 2007/2008 harvest.

The length of vegetative shoots seemed to increase when NAA was applied at 200 mg L^{-1}. The increase in vegetative shoot growth is likely an indirect effect of the reduction in fruit numbers (Dag et al., 2010). A heavy crop load is a very strong carbohydrate sink that receives resources at the expense of shoot growth (Dag et al., 2009; Lavee, 2006). However, NAA at 400 mg L^{-1} did not increase vegetative growth compared to the control despite a substantial reduction in fruit number. In fact, the least vegetative growth occurred at this NAA concentration and this can possibly be attributed to the phytotoxic symptoms observed on shoots a week after application (personal observation). Dag et al. (2009) found that NAA applied at 320 mg L^{-1} damaged the new shoot growth in 'Barnea' in spring, but resulted in increased auxiliary growth later in the season. Since our assessment of vegetative growth included all new shoot growth, it appears that NAA at 400 mg L^{-1} stunted vegetative growth in 'Mission' and this may decrease yield in the subsequent season due to a decrease in bearing positions.

In our second experiment, we aimed to determine the number of fruit per unit shoot length that would optimise fruit quality and yield. Our intention was to investigate the possibility of developing a practical guideline that growers can use to determine the level of thinning required. Fruit size decreased linearly from 18 to10 fruit per meter one-year-old shoot length (Table 4). Additional thinning did not further increase fruit size. Hence, from a fruit size perspective, thinning to a crop load of less than 10 fruit per meter shoot length would be wasteful. The thinning severity that will optimise yield and income may differ from the thinning level that will optimise fruit size and therefore the number of fruit per meter one-year-old shoot length should have been equated to the yield and income per tree. This could be done in future studies.

Conclusion

NAA effectively thinned 'Mission' olives and increased fruit quality (bigger fruit size and a higher proportion of black fruit) in the "on" season. Even with a yield reduction of 32%, no difference in income was seen due to an increase proportion of high quality table olives. It is advised that NAA concentrations higher than 200 mg L^{-1} should only be used in

definite “on” seasons, as a severe thinning effect might be achieved at higher NAA concentrations. To decrease the cost of treatment, earlier (10 instead of 15 DAFB) NAA application at lower concentrations should be considered since the efficacy of NAA is higher when applied prior to 15 DAFB (Sibbett & Krueger, 1998).

Literature cited

Andreini, L., Bartolini, S., Guivarc'h, A., Chriqui, D., Vitagliano, C., 2008. Histological and immunohistochemical studies on flower induction in the olive tree (*Olea europaea* L.). Plant Biol. 10: 588-595.

Baktir, I., Ulger, S. & Himelrick, D.G., 2004. Relationship of seasonal changes in endogenous plant hormones and alternate bearing of olive trees. HortScience. 39: 987-990.

Dag, A., Bustan, A., Avni, A., Lavee, S. and Riov, J., 2009. Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees. Crop Pasture Sci. 60: 1124 - 1130.

Dag, A., Bustan, A., Avni, A., Tzipori, I., Lavee, S. and Riov, J., 2010. Timing of fruit removal affects concurrent vegetative growth and subsequent return bloom and yield in olive (*Olea europaea* L.). Sci. Hort. 123: 469-472.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Fernández-Escobar, R., Benlloch, M., Navarro, C. & Martin, G.C., 1992. The time of floral induction in olive. J. Am. Soc. Hort. Sci. 117: 304-307.

Harley, C.P., Moon, H.H. & Regeimbal, L.O., 1958. Evidence that post-bloom apple-thinning sprays of naphthalene acetic acid increase blossom-bud formation. Proc. Amer. Soc. Hort. Sci. 72: 52-56.

Hartmann, H.T., 1951. Time of floral differentiation of the olive in California. Bot. Gaz. 112: 323-327.

Hartmann, H.T., 1952. Spray thinning of olives with Naphthalene acetic acid. Proc. Amer. Soc. Hort. Sci. 59: 187-195.

Krueger, W. H., Heath, Z. R. & Mulqueeny, B., 2002. Effect of spray solution concentration, active ingredient, certain additives and sequential treatments of naphthalene acetic acid for chemical thinning of Manzanillo table olives. Acta Hort. 586: 267-271.

Krueger, W.H., Maranto, J. & Sibbett, G.S., 2004. Olive fruit thinning. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Ed.) Pp. 101-104. University of California, Oakland, California, USA.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Lavee, S., 2006. Biennial bearing in olive (*Olea europaea L.*). FAO Network. Olea 25: 5-12. July 2006.

Link, H., 2000. Significance of flower and fruit thinning on fruit quality. Plant Growth Regul. 31:17-26.

Martin, G.C., Connell, J.H., Freeman, M.W., Krueger, W.H. & Sibbett, G.S., 1994. Efficacy of foliar application of two naphthaleneacetic acid salts for olive fruit thinning. Acta Hort. 356: 302-305.

Martin, G.C., Lavee, S., Sibbett, G. S., Nishijima, S. & Carlson, S. P., 1980. A new approach to thinning olives. Calif. Agric., 34: 7-8.

Monselise, S.P. & Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. Hort. Rev. 4: 128-173.

Proietti, P., 2003. Changes in photosynthesis and fruit characteristics in olive. Photosynthetica. 40 (4): 559-564.

Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., & Meier, U., 2002. Phenological growth stages of olive trees (*Olea europaea*). Ann. Appl. Biol. 140: 151-157.

Sibbett, G.S. & Krueger, W.H., 1998. Olive spray thinning guidelines. University of California, Agriculture and Natural Resources Publication 2475, Oakland, California, USA.

Stutte, G.W. & Martin, G.C., 1986. Effect of killing the seed on return bloom of olive. Sci Hort. 29: 107-113.

Sutter, E.G., 2004. Olive cultivars and propagation. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Ed.) Pp. 20. University of California, Oakland, California, USA.

Williams, K.M. & Fallahi, E., 1999. The effects of exogenous bioregulators and environment on regular cropping of apple. HortTechnology. 9(3): 323-327.

Table 1. The effect of NAA application in 2007/2008 on percentage fruit set in 'Mission' olives.

Treatment	2007/2008
Control	81.88 a[y]
NAA 100 mg·L^{-1}	73.81 a
NAA 150 mg·L^{-1}	72.82 ab
NAA 200 mg·L^{-1}	64.60 b
Pr > F	
Treatment	*0.0088*
NAA vs Control	*0.0047*
NAA Lin	*0.0754*
NAA Quad	*0.1930*

[y] *means with different letters differ significantly at p<0.05*

Table 2. The effect of NAA application in 2008/2009 on fruit set percentage, vegetative growth and number of 'Mission' fruit harvested in the season of application.

Treatment	Fruit set %	Vegetative ratio [R]	Estimated number of fruit
Control	53.01 a	0.19 b	18376 a[y]
NAA 100 mg·L^{-1}	13.95 b	0.20 b	12156 b
NAA 200 mg·L^{-1}	11.67 b	0.28 a	10817 b
NAA 400 mg·L^{-1}	9.67 b	0.18 b	6808 c
Pr > F			
Treatment	*<0.0001*	*0.0514*	*<0.0001*
NAA vs Control	*<0.0001*	*0.2980*	*<0.0001*
NAA Lin	*0.3132*	*0.3246*	*0.0067*
NAA Quad	*0.8125*	*0.0154*	*0.7898*

[y] *means with different letters differ significantly at p<0.1*

[R] *One year old shoot length divided by one and two year old shoot length*

Table 3. The effect of NAA application in 2008/2009 on the pip to fruit diameter ratio of 'Mission' olives.

Treatment	Black fruit	Average of all fruit
Control	0.423 NS	0.442 c[z]
NAA 100 mg·L^{-1}	0.422	0.422 bc
NAA 200 mg·L^{-1}	0.450	0.395 ab
NAA 400 mg·L^{-1}	0.411	0.384 a
Pr > F		
Treatment	*0.3840*	*0.0032*
NAA vs Control	*0.7960*	*0.0029*
NAA Lin	*0.6521*	*0.0207*
NAA Quad	*0.1011*	*0.3216*

[NS] *no significant differences between treatments*

[z] *means with different letters differ significantly at p<0.05*

Table 4. The effect of thinning by hand in 2008/2009 on the percentage fruit remaining at harvest, pip to flesh ratio, vegetative growth during the year of application, fruit weight and diameter as well as number of fruit per meter one-year-old shoot length.

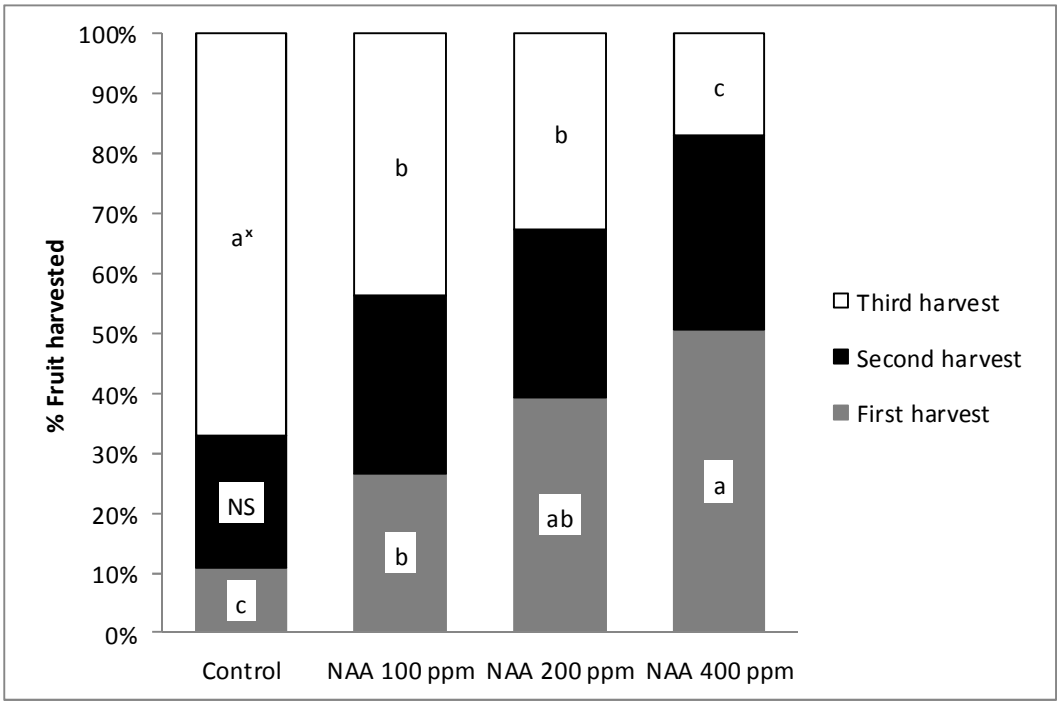
Thinning severity	Fruit % at harvest (compared to original fruit number at onset of trial)	Pip to fruit ratio	Vegetative ratio ^	Fruit weight (g)	Fruit diameter (mm)	Number of fruit per meter shoot length
0% Thinning)	95 a[y]	0.47 a	0.10 NS	2.9 a	16.3 a	18 a
10% Thinning	90 a	0.47 a	0.10	3.0 a	16.2 a	17 a
25% Thinning	80 b	0.46 ab	0.12	3.3 ab	16.7 ab	13 b
50% Thinning	55 c	0.44 b	0.16	3.7 b	17.0 b	10 bc
75% Thinning	38 d	0.45 ab	0.13	3.7 b	17.3 b	7 c
Pr > F						
Treatment	<0.0001	0.0892	0.2925	0.0558	0.0372	<0.0001
Lin	<0.0001	0.0089	0.0661	0.0035	0.0024	<0.0001
Quad	0.0002	0.5175	0.4910	0.9572	0.9715	0.8813

[NS] *no significant differences between treatments*

[y] *means with different letters differ significantly at p<0.1*

[^] *One year old shoot length divided by one and two year old shoot length*

[T] *Fruit thinned*

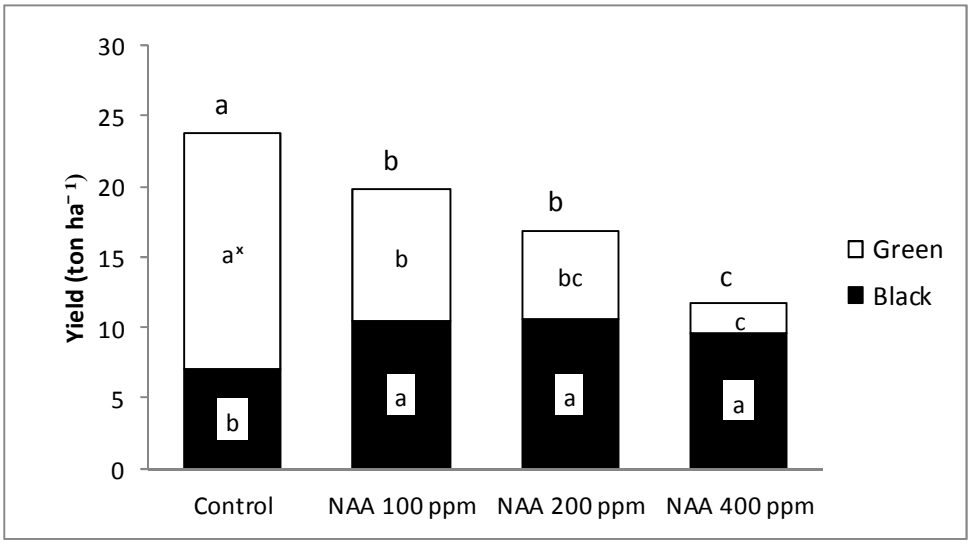


Pr > F	First harvest (5 May 2009)	Second harvest (8 June 2009)	Third harvest (11 June 2009)
Treatment	*<0.0001*	*0.0930*	*<0.0001*
NAA vs Control	*<0.0001*	*0.0241*	*<0.0001*
NAA Lin	*0.0015*	*0.3611*	*0.0012*
NAA Quad	*0.4095*	*0.4726*	*0.7344*

[NS] *no significant differences between treatments*

[x] *means with different letters differ significantly at p<0.05*

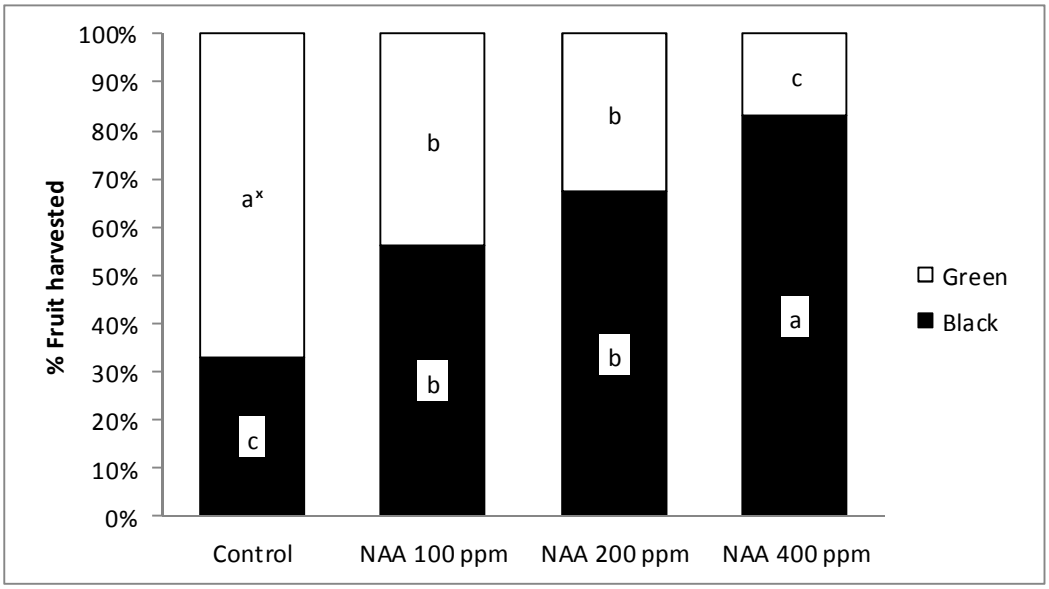
Figure 1. The effect of NAA application in 2008 on harvest distribution of 'Mission' olives in the season of application. Harvest occurred on 5 May, 8 and 11 June 2009. Only fruit that were black and exceeded a minimum weight of approximately 4 g were picked during the first two selective harvests. All remaining fruit, which were green in colour, were picked on 11 June 2009.



Pr > F	Black fruit	Green fruit	Total yield
Treatment	*0.0066*	*< 0.0001*	*0.0007*
NAA vs Control	*0.0009*	*< 0.0001*	*0.0010*
NAA Lin	*0.4026*	*0.0053*	*0.0038*
NAA Quad	*0.5533*	*0.7841*	*0.9184*

[x] *means with different letters differ significantly at p<0.05*

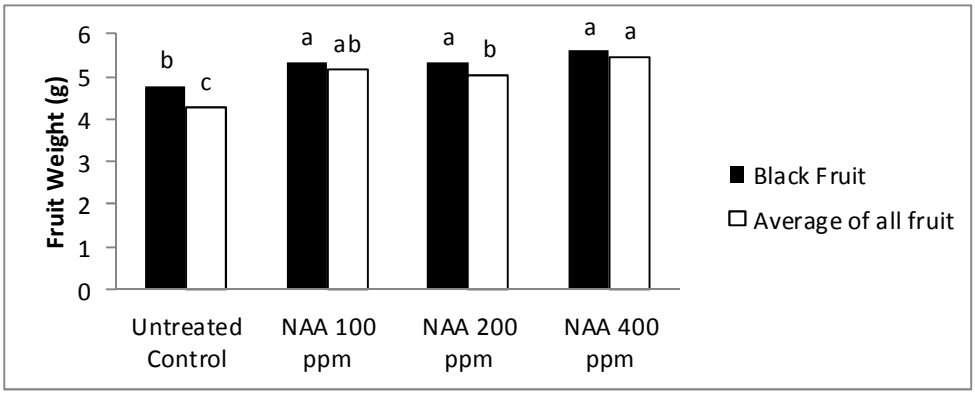
Figure 2. The effect of NAA application in 2008/2009 on yield of black fruit and total yield of 'Mission' olives in the season of application.



Pr > F	% Black fruit
Treatment	*<0.0001*
NAA vs Control	*<0.0001*
NAA Lin	*0.0012*
NAA Quad	*0.7344*

[x] means with different letters differ significantly at p<0.05

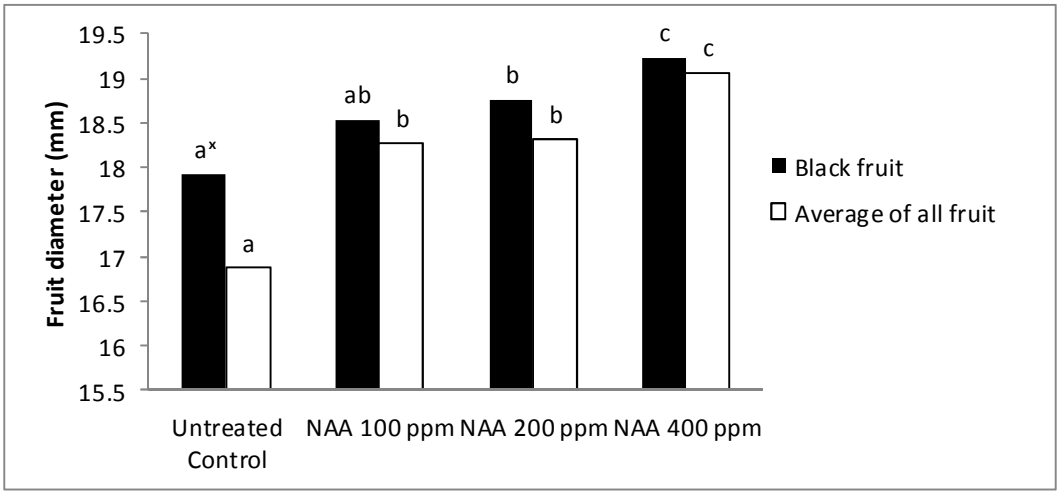
Figure 3. The effect of NAA application in 2008/2009 on fruit colour distribution of 'Mission' olives in the season of application.



Pr > F	Black Fruit	Average of all fruit
Treatment	*<0.0001*	*<0.0001*
NAA vs Control	*<0.0001*	*<0.0001*
NAA Lin	*0.0604*	*0.0480*
NAA Quad	*0.2647*	*0.1779*

** means within a harvest date with different letters differ significantly at p<0.05*

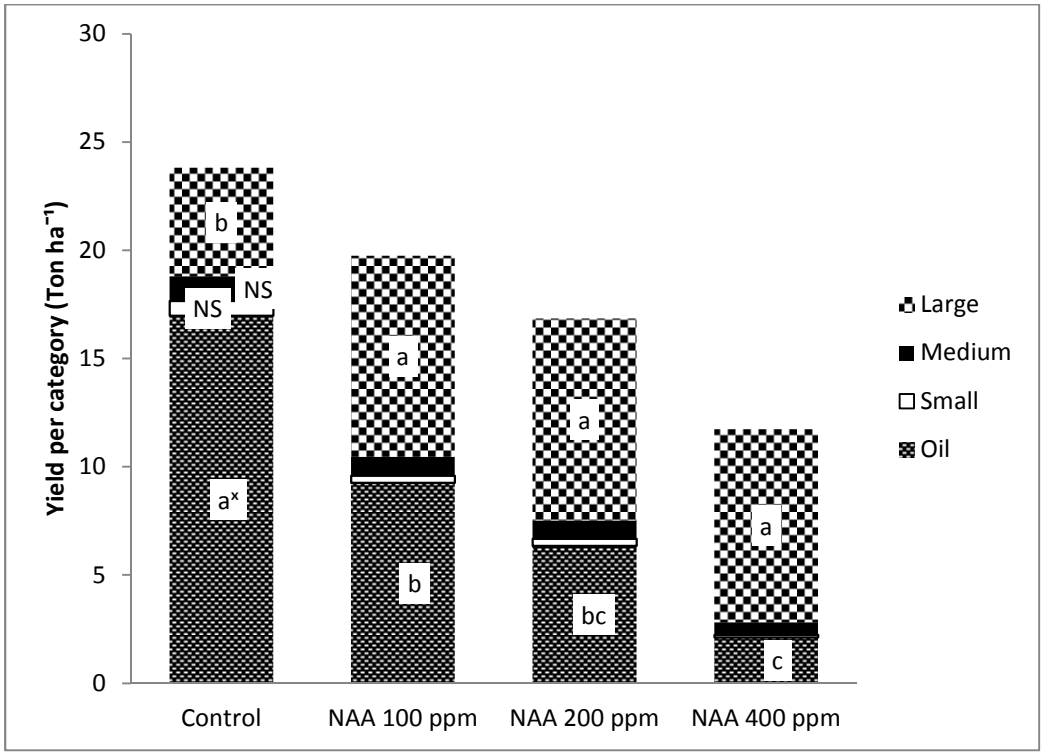
Figure 4. The effect of NAA application in 2008/2009 on black and average fruit weight of 'Mission' olives in the season of application.



Pr > F	Black fruit	Average of all fruit
Treatment	*0.0003*	*<0.0001*
NAA vs Control	*0.0002*	*<0.0001*
NAA Lin	*0.0114*	*0.0016*
NAA Quad	*0.5864*	*0.3064*

[x] means with different letters differ significantly at p<0.05

Figure 5. The effect of NAA application in 2008/2009 on black and average fruit diameter of 'Mission' olives in the season of application.

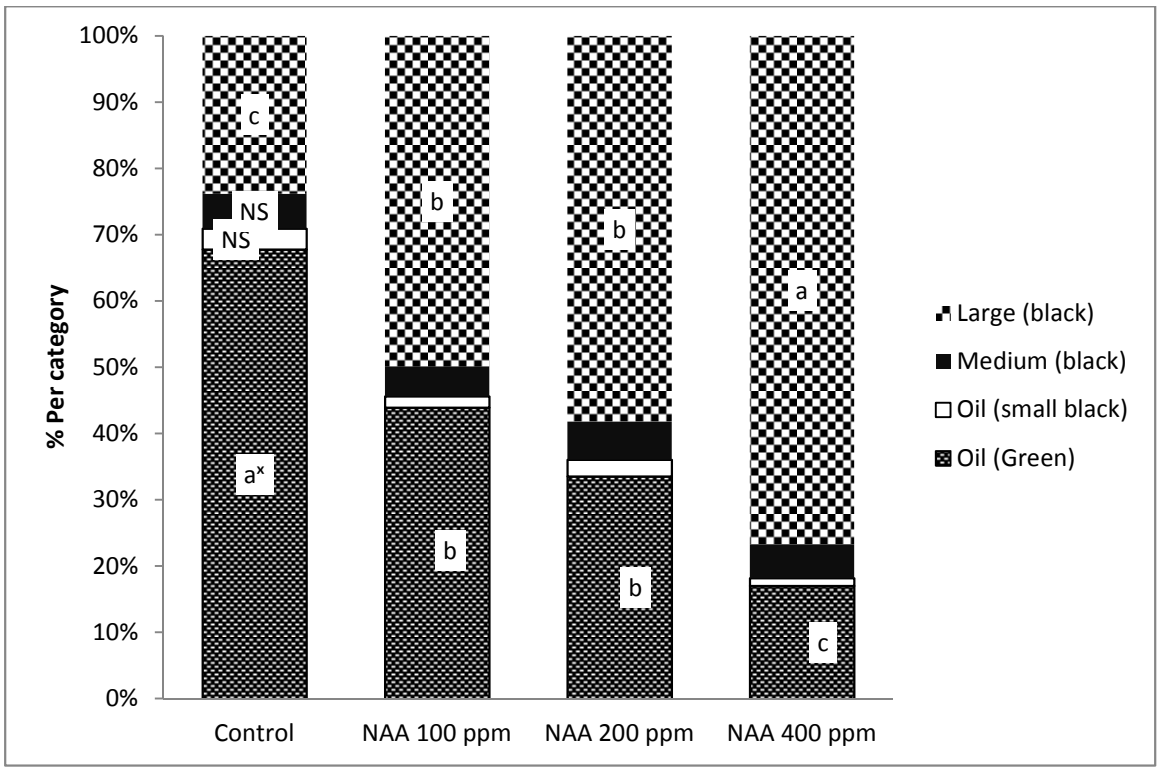


Pr > F	Oil	Standard (3.3 – 4 g)	Medium (4 – 4.55 g)	Large (4.55 g)
Treatment	*<0.0001*	*0.0520*	*0.1118*	*0.0004*
NAA vs Control	*<0.0001*	*0.0124*	*0.0464*	*<0.0001*
NAA Lin	*0.0054*	*0.2471*	*0.1613*	*0.6729*
NAA Quad	*0.7612*	*0.6677*	*0.6925*	*0.8620*

[x] means within a fruit size category with different letters differ significantly at p<0.05

NS = non-significant

Figure 6. The effect of NAA application in 2008/2009 on yield per category of 'Mission' olives in the season of application.

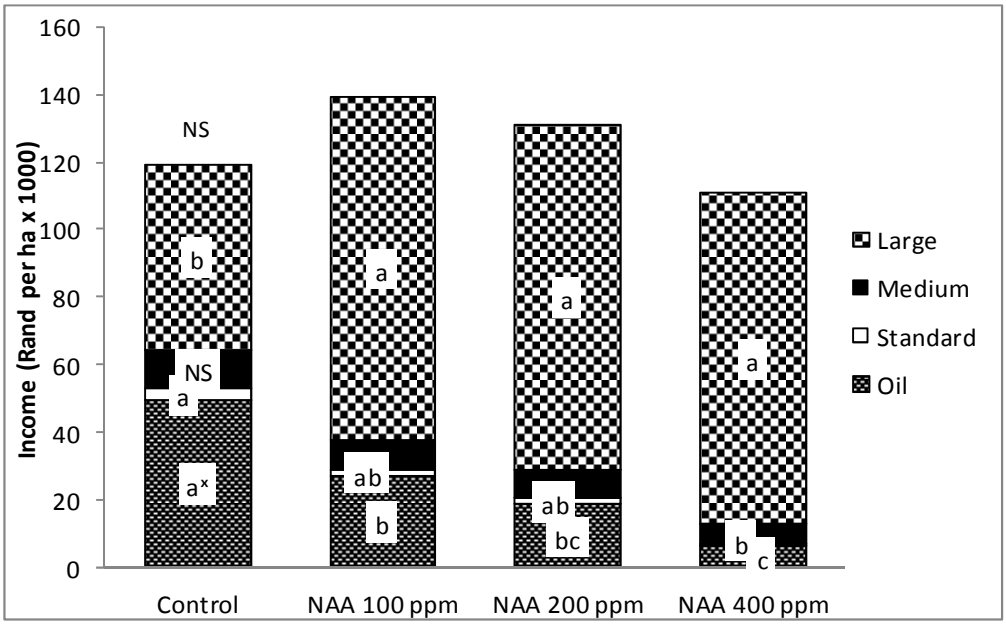


Pr > F	Oil	Standard (3.3 – 4 g)	Medium (4 – 4.55 g)	Large (4.55 g)
Treatment	*<0.0001*	*0.3038*	*0.9247*	*<0.0001*
NAA vs Control	*<0.0001*	*0.1414*	*0.9184*	*<0.0001*
NAA Lin	*0.0009*	*0.5049*	*0.8103*	*<0.0001*
NAA Quad	*0.8241*	*0.3116*	*0.5335*	*0.9182*

[NS] *no significant differences between treatments*

[x] *means within a fruit size category with different letters differ significantly at p<0.05*

Figure 7. The effect of NAA application in 2008/2009 on category distribution of 'Mission' olives in the season of application.



Pr > F	Oil	Standard (3.3 – 4 g)	Medium (4 – 4.55 g)	Large (4.55 g)	Total income
Treatment	*<0.0001*	*0.0520*	*0.1118*	*0.0004*	*0.1709*
NAA vs Control	*<0.0001*	*0.0124*	*0.0464*	*<0.0001*	*0.4921*
NAA Lin	*0.0048*	*0.2471*	*0.1613*	*0.6729*	*0.0357*
NAA Quad	*0.7941*	*0.6677*	*0.6925*	*0.8620*	*0.9137*

[NS] *no significant differences between treatments*

[x] *means within a fruit size category with different letters differ significantly at p<0.05*

Figure 8. The effect of NAA application in 2008/2009 on income per ha of 'Mission' olives in the season of application.

Paper 3. Evaluate the use of NAA to thin 'Manzanillo' olives in the "on'' year to improve fruit quality and decrease alternate bearing under South African conditions.

Abstract. Olive growers are faced with major challenges due to alternate bearing, which the olive is genetically predisposed to. High fruit numbers in the "on" season decreases flower initiation resulting in a subsequent "off" season. Chemical fruit thinning early in the "on" season with naphthalene acetic acid (NAA), is widely used in various olive growing regions of the world to reduce fruit numbers and increase fruit quality (primarily fruit size) in the "on" season, and increase fruit numbers in the "off" season. NAA has not been used for olive thinning in South Africa and the effective concentrations for local conditions and cultivars are not known. 'Manzanillo' olives are grown for table purposes only as the amount of oil accumulated in fruit is low. Fruit are harvested green and fruit quality is mainly determined by fruit size. In the current study, NAA was applied to 'Manzanillo' olive trees at 100, 200 and 400 mg L^{-1} in the 2008/09 season to determine the optimum concentration under South African conditions. On average, NAA decreased total fruit number by 35% and reduced yield by 24%. Due to an increase in fruit size in response to fruit thinning, the income per ha did not differ between treatments. The extent on thinning and fruit size increased with an increase in NAA concentration from 100 mg L^{-1} to 200 mg L^{-1}, but no further benefit was attained with an increase in concentration to 400 mg L^{-1}. Despite the significant decrease in yield in response to NAA application, return bloom showed no response to NAA application. However, flowering was poor throughout the region, even in orchards that were supposed to experience an "on" season.

Introduction

Alternate bearing in olives is a common occurrence in all production regions throughout the world (Krueger et al., 2004; Lavee, 1996). Yield may fluctuate from 0 ton ha^{-1} in "off" seasons to 30 ton ha^{-1} in "on" seasons (Lavee, 1996). With fruit size being the main determining factor for fruit quality in 'Manzanillo', Krueger et al. (2004) found that fruit quality of this cultivar decreased linearly with an increase in yield. Major losses in profit are incurred in "on" seasons due to fruit being too small for table olive usage (Lavee, 2006) while in an "off" season, the increase in fruit size does not make up for the loss in yield (Krueger et al., 2004). In addition, alternate bearing brings about severe management

challenges with regard to all general horticultural farming practices (e.g., labour, operating and utilizing storage and processing facilities) (Monselise and Goldschmidt, 1982).

The degree of flower initiation correlates negatively with the number of seeds present on olive trees (Stutte and Martin, 1986). Developing seeds produce high levels of gibberellic acids (GAs) that negatively influence flower initiation (Fabbri and Benelli, 2000; Lavee, 1996). Apart from the direct negative effect of seeds on flower initiation, a heavy crop load tends to negatively affect vegetative growth and total shoot length (Connor and Fereres, 2005). The heavy crop load of an "on" season is a very strong carbohydrate sink that receives resources at the expense of shoot growth (Lavee, 1996). Since flowers form exclusively on one-year-old shoots, the decrease in vegetative growth in an "on" season may also contribute to a decrease in fruiting positions, causing a low crop in the next season (Krueger et al., 2004).

Excessive yield should be reduced early in the "on" season to obtain satisfactory fruit quality and overcome biennial bearing. Fruit removal should occur before the flower induction (FI) period of next years crop, as removal of fruit hereafter will only affect the crop load of the current season (Williams and Fallahi, 1999). Olive FI happens as early as 7 to 8 weeks after full bloom (FB) at roughly the same time as pit hardening (endocarp sclerification) of the current crop (Baktir et al., 2004; Fernández-Escobar et al., 1992; Sanz-Cortés et al., 2002).

Fruit thinning improves fruit quality and reduces alternate bearing in various crops (Link, 2000). In Olives, the main method currently used to break the alternation cycle in the table olive industry is "on" season thinning (Dag et al., 2009). Fruit thinning approximately two weeks after full bloom (FB) increased vegetative growth, flower bud differentiation, fruit size and cumulative yield of consecutive years in various table and oil olive cultivars (Dag et al., 2009; Krueger et al., 2002; Lavee, 2006; Martin et. al., 1994). Crop load reduction with chemical fruit thinning increases the leaf to fruit ratio and is much more effective than pruning, which maintains this ratio (Krueger et al., 2004).

Chemical thinning of olives with the synthetic auxin, naphthalene acetic acid (NAA), has been done in California since the 1950's (Hartmann, 1952). Application of NAA at 100 mg

L^{-1} 10 days after full bloom (DAFB), with the addition of 10 mg L^{-1} per day until 20 DAFB, effectively thins and reduces yield fluctuations in various table olive cultivars (Lavee and Spiegel, 1958, 1967; Martin et al., 1980). NAA positively influenced fruit quality, i.e., fruit size, flesh-to-pit ratio and oil content (Martin et al., 1980) and improved return bloom (Lavee, 2006).

Chemical thinning of olives is not a standard practice in South Africa. Until now, South African olive producers opted to endure the negative effects of alternate bearing. However, a continuous increase in input costs and competitiveness in pricing (stagnation of selling price in recent seasons) is forcing producers to farm more efficiently. Since chemical thinning of olives with NAA has not been tested under South African conditions, experiments were initiated to establish the optimum application rates for local conditions for 'Manzanillo'.

Material and Methods

Plant material.

Experiments were conducted in the 2008/2009 season at Buffet Olives, Paarl (Latitude 33°45'S, Longitude 18°56'E) in the Mediterranean-type climate Western Cape Province of South Africa in a 'Manzanillo' orchard planted in 1993 at a spacing of 7 x 4.5 m. Trees have an average canopy volume of 28 m^3.

Treatments.

NAA (Planofix, Bayer CropScience AG, Isando, South Africa) was applied at 100, 200 and 400 mg L^{-1}, 15 DAFB on 6 November 2008 at an average fruit size of 2.9 mm. Treatments, including the untreated control, were randomized in 10 blocks with two trees per plot, guard trees between plots and guard rows between treatment rows. NAA was applied early on wind still mornings with a truck-mounted motorized sprayer until run off. Each tree received ca. 6 L of the spray mixture. No wetting agent was used as per Bayer CropScience recommendation.

Fruit set.

Three one-year-old shoots of about 20 cm long (ca. 15 fruit per shoot) per tree were selected and the number of fruit per shoot counted on the day of NAA application. Fruit were again counted on 19 January 2009 after the fruit drop period and fruit set was calculated.

Fruit quality at harvest.

Trees were harvested on 9, 18, 23 and 24 (twice on this day) March 2009. Only fruit that exceeded an estimated minimum size (harvesters are trained to select the biggest fruit) were picked during the first four selective harvests while all remaining fruit were harvested immediately after the fourth and final selective picking. A 20-fruit sample per treatment plot was randomly collected on each harvest date to determine average fruit and pip diameter (measured by electronic calliper), the pip-to-flesh ratio and average fruit weight. Fruit number per tree was estimated by dividing the total fruit weight per tree by the average fruit weight of the 20-fruit sample.

Economic analysis.

'Manzanillo' olives are divided into four size categories according to South African industry size standards, viz. large (>4.55 g), medium (4 – 4.55 g), standard (3.3 – 4 g) and oil (<3.3 g). To determine the percentage of the crop per size category according to fruit weight, the average fruit diameters and average fruit weights of treatment replications were plotted and a linear regression line fitted to the data. Individual fruit weights of the 20 fruit per treatment replicate were determined by inserting fruit diameters into the equation obtained from the regression line. Prices varied between categories, viz. R2.40/kg for small fruit (<3.3 g), R4.50/kg for standard, R6.50/kg for medium and R9/kg for large fruit (Scrimgeour, personal communication 2011). Yield per category, income per category and category distribution were determined. Income per ha was determined for each treatment by adding the incomes per category.

Vegetative growth.

All new vegetative shoot growth emanating from the ca. 20 cm-long shoots used to assess fruit set was measured in winter. The ratio of one-year-old shoot growth to total shoot length was determined as indication of vegetative growth.

Return bloom.

Trees were scored visually at FB (16 October 2009) from 0 to 5 where 0 represents zero flowers and 5 represents a very heavy bloom. Since, virtually no flowers were present for any of the treatments, no meaningful yield was obtained. Hence, yield and fruit quality data for the second season could not be recorded.

Statistical analysis.

Data were analysed with the General Linear Models (GLM) procedure of the SAS (Statistical Analysis System) computer program (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC., USA). Orthogonal linear and quadratic contrasts for NAA concentration as well as a contrast for comparison of NAA with the control were included in the analysis.

Results and discussion

'Manzanillo' table olives have four different payment categories according to fruit size. Fruit weighing less than 3.3 g have a low value as these fruit can only be used for oil production, while larger table olive fruit are worth much more than smaller fruit. In "on" seasons, a high yield of small fruit is obtained while the increase in fruit size in the subsequent "off" seasons does not offset the decrease in yield. Considering the above, it seems that income in 'Manzanillo' orchards can be maximised by decreasing yield alternation and thereby ensuring a regular yield of good quality fruit. Yield alternation can be decreased by chemically thinning fruit in the "on" season with NAA. In previous research on 'Manzanillo', Krueger et al. (2002) found that the value of table olives per ton of fruit produced increased with an increase in NAA concentration from 150 to 300 (1999 season) and from 150 to 450 mg L^{-} (1997 season) due to an increase in thinning resulting in an increase in fruit size.

Similar to the results of Krueger et al. (2002), NAA treatment decreased fruit set (81 to 49%), the number of fruit per tree (by 31%) (Table 1) and total yield (20.8 to 16.2 ton ha^{-1}) (Fig. 1) compared to the control. The decrease in fruit numbers per tree was offset by an increase in average fruit weight (Fig. 2) and fruit diameter (Fig. 3) compared to the control. Fruit set showed a quadratic response ($p = 0.0006$) to NAA concentration in that set decreased with an increase in NAA concentration to 200 mg L^{-1}, but did not decrease any

further with an increase in concentration to 400 mg L^{-1}. Hence, contrary to the findings of Krueger et al. (2002), increasing NAA concentration from 200 to 400 mg L^{-1} did not seem to have an additional thinning effect and, therefore, also did not seem to affect the number of fruit per tree (Table 1), yield (Figure 1) and fruit size (Figures 2 and 3). However, the extent of thinning as well as the effect of thinning on fruit numbers, yield and fruit size did increase from 100 mg L^{-1} to 200 mg L^{-1} NAA. NAA application at 200 mg L^{-1} and 400 mg L^{-1} decreased the pip to fruit ratio compared to the control (Table 1). The average pip to fruit ratio decreased linearly with an increase in NAA concentration ($p = 0.0079$).

Due to its effect on fruit size, NAA significantly decreased the yield of oil olives and small fruit while 200 mg L^{-1} and 400 mg L^{-1} NAA increased the yield of large olives compared to the control (Figure 4). Consistent with the effect of NAA concentration on fruit size, oil olives and small fruit decreased with an increase in NAA concentration to 200 mg L^{-1}, but did not decrease any further with an increase in concentration to 400 mg L^{-1}. For large olives, the opposite was found in that yield in this category did not show a further increase with an increase in NAA concentration from 200 to 400 mg L^{-1}. No treatment effect was found for yield of medium size olives. NAA significantly decreased the percentage of the crop in the oil category and increased the percentage of the crop in the medium category (Figure 5). The two highest NAA concentrations (200 and 400 mg L^{-1}) significantly increased the percentage of the crop in the large category. The percentage of the crop in the large category increased linearly with an increase in NAA concentration. The two highest NAA concentrations increased the percentage of the crop in the medium and decreased the percentage of the crop in the oil category compared to the lowest NAA concentration (Figure 5).

To qualify as table olives, ‘Manzanillo’ fruit need to fall into the standard (3.3 - 4 g), medium (4 – 4.55 g) or large (>4.55 g) size categories. All fruit not qualifying according to the harvesting criteria are used for the production of olive oil. The value of ‘Manzanillo’ fruit increases with an increase in size. ‘Manzanillo’ olive prices are R2.40 per kg for oil, R4.50 per kg for standard, R6.50 for medium and R9 per kg for fruit qualifying as large fruit. With these price ranges in mind, a higher income can be generated theoretically with less fruit, but of a higher quality. In accordance with the above, no difference in total income per ha was found between treatments (Figure 6) despite the considerable thinning of fruit in response to

NAA application. While NAA application decreased the income for oil and small olives compared to the control, the two highest NAA concentrations increased the income for large olives compared to the control. The two highest NAA concentrations also increased the income for large olives and decreased the income for oil and small olives compared to the lowest NAA concentration. The significant lower yield of the two higher NAA concentrations was offset by a much higher income from the large category. Although not measured in this trial, it was suggested by Krueger et al. (2004) that indirect costs per hectare will be less due to less harvesting, handling, transport and factory expenses with lower yields of larger fruit.

When considering that big fruit are selectively picked at the first harvest, the effect of NAA on fruit size was of sufficient extent to increase the proportion of the crop removed at the first harvest ($p = 0.0007$) and decrease the percentage of the crop harvested on the final harvest date ($p = 0.0002$) compared to the untreated control (Figure 7). The two higher NAA concentrations increased the percentage of the crop harvested on the third harvest date compared to the control and the percentage of the crop harvested on this date increased linearly with an increase in NAA concentration ($p = 0.0132$). No treatment effect was obtained on the second and fourth harvest dates. Although not the case in this experiment, fewer harvests would theoretically be needed for trees thinned with NAA.

Vegetative growth increased linearly with increasing NAA concentration ($p = 0.0179$) and the two highest NAA concentrations increased vegetative growth compared to the control (Table 1), most probably due to relatively lower yields resulting in supplementary vegetative growth. A heavy crop load is a very strong carbohydrate sink that receives resources at the expense of shoot growth (Dag et al., 2009; Lavee, 2006). When taking into account that flowers form exclusively on one-year-old shoots, the increased vegetative shoot growth in response to the two higher NAA concentrations could increase yield in the subsequent season by increasing the number of potential bearing positions (Krueger et al., 2004).

No return bloom was observed for any of the treatments and no assessment of yield and fruit quality was possible. Adjacent orchards and farms also did not have any return bloom. This was probably due to climatic limitations for floral formation, as even trees that were

supposed to have an “on” season did not flower. Climatic conditions are known to affect flower initiation and differentiation in olive (Lavee, 1996).

Conclusion

The current research suggests that the net income of ‘Manzanillo” orchards can be increased by fruit thinning in the “on” season with NAA. NAA application at 200 mg L^{-1} is recommended to increase the yield of fruit in the large category. Although we could not assess the effect of NAA application on the return bloom, thinning with NAA should also decrease yield alternation based on previous research.

Literature cited

Baktir, I., Ulger, S. & Himelrick, D.G., 2004. Relationship of seasonal changes in endogenous plant hormones and alternate bearing of olive trees. HortScience. 39: 987-990.

Connor, D.J. & Fereres, E., 2005. The physiology and adaptation of yield expression in olive. Hort. Rev. 31, 155-229.

Dag, A., Bustan, A., Avni, A., Lavee, S. & Riov, J., 2009. Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees. Crop Pasture Sci. 60: 1124 - 1130.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Fernández-Escobar, R., Benlloch, M., Navarro, C. & Martin, G.C., 1992. The time of floral induction in olive. J. Am. Soc. Hort. Sci. 117: 304-307.

Hartmann, H.T., 1952. Spray thinning of olives with Naphthalene acetic acid. Proc. Amer. Soc. Hort. Sci. 59: 187-195.

Krueger, W. H., Heath, Z. R. & Mulqueeny, B., 2002. Effect of spray solution concentration, active ingredient, certain additives and sequential treatments of naphthalene acetic acid for chemical thinning of Manzanillo table olives. Acta Hort. 586: 267-271.

Krueger, W.H., Maranto, J. & Sibbett, G.S., 2004. Olive fruit thinning. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Ed.) Pp. 101-104. University of California, Oakland, California, USA.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Lavee, S., 2006. Biennial bearing in olive (*Olea europaea L.*). FAO Network. Olea 25: 5-12. July 2006.

Lavee, S. & Spiegel, P., 1958. Spray thinning of olives with growth regulators. Ktavim 9:129-138.

Lavee, S. & Spiegel, P., 1967. The effect of time of application of two growth substances on the thinning of olive fruit. Proc. Amer. Soc. Hort. Sci. 91:180-185.

Link, H., 2000. Significance of flower and fruit thinning on fruit quality. Plant Growth Regul. 31:17-26.

Martin, G.C., Connell, J.H., Freeman, M.W., Krueger, W.H. & Sibbett, G.S., 1994. Efficacy of foliar application of two naphthaleneacetic acid salts for olive fruit thinning. Acta Hort. 356: 302-305.

Martin, G.C., Lavee, S., Sibbett, G. S., Nishijima, S. & Carlson, S. P., 1980. A new approach to thinning olives. Calif. Agric., 34: 7-8.

Monselise, S.P. & Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. Hort. Rev. 4: 128-173.

Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., & Meier, U., 2002. Phenological growth stages of olive trees (*Olea europaea*). Ann. Appl. Biol. 140: 151-157.

Stutte, G.W. & Martin, G.C., 1986. Effect of killing the seed on return bloom of olive. Sci Hort 29: 107-113.

Tromp, J., 2000. Flower-bud formation in pome fruits as affected by fruit thinning. Plant Growth Regul. 31, 27-34.

Williams, K.M. & Fallahi, E., 1999. The effects of exogenous bioregulators and environment on regular cropping of apple. HortTechnology. 9(3): 323-327.

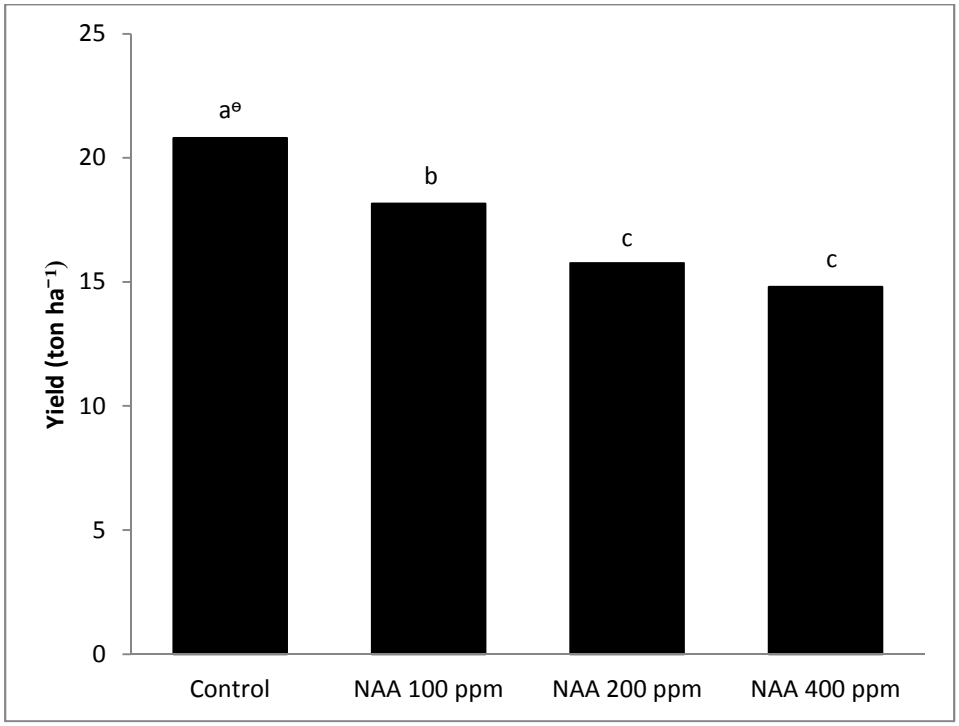
Table 1: The effect of NAA application in 2008/2009 on fruit set percentage, number of 'Manzanillo' fruit harvested, diameter pip to fruit ratio and vegetative growth during the year of application. Means were separated by LSD (5%).

Treatment	Fruit set %	Estimated number of fruit	Average diameter pip to fruit ratio	Vegetative ratio^
Control	81 a[y]	18636 a	0.492 c	0.144 b
NAA 100 mg·L^{-1}	62 b	14906 b	0.483 bc	0.182 b
NAA 200 mg·L^{-1}	42 c	12193 c	0.474 ab	0.251 a
NAA 400 mg·L^{-1}	44 c	11132 c	0.467 a	0.261 a
Pr > F				
Treatment	*<0.0001*	*<0.0001*	*0.0004*	*0.0020*
NAA vs Control	*<0.0001*	*<0.0001*	*0.0004*	*0.0020*
NAA Lin	*0.0011*	*0.0019*	*0.0079*	*0.0179*
NAA Quad	*0.0006*	*0.3926*	*0.4073*	*0.2878*

[y] *means with different letters differ significantly at p<0.05*

[NS] *no significant differences between treatments*

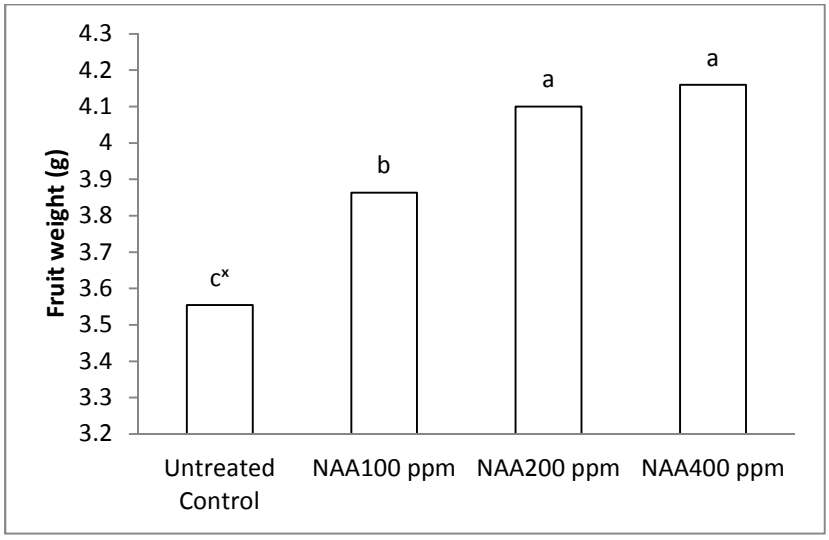
^One year old shoot length divided by one and two year old shoot length



Pr > F	2008/2009
Treatment	*<0.0001*
NAA vs Control	*<0.0001*
NAA Lin	*0.0071*
NAA Quad	*0.2520*

[θ]means *with different letters differ significantly at p<0.05*

Figure 1: The effect of NAA application in 2007/2008 on yield of 'Manzanillo' olives in the season of application.

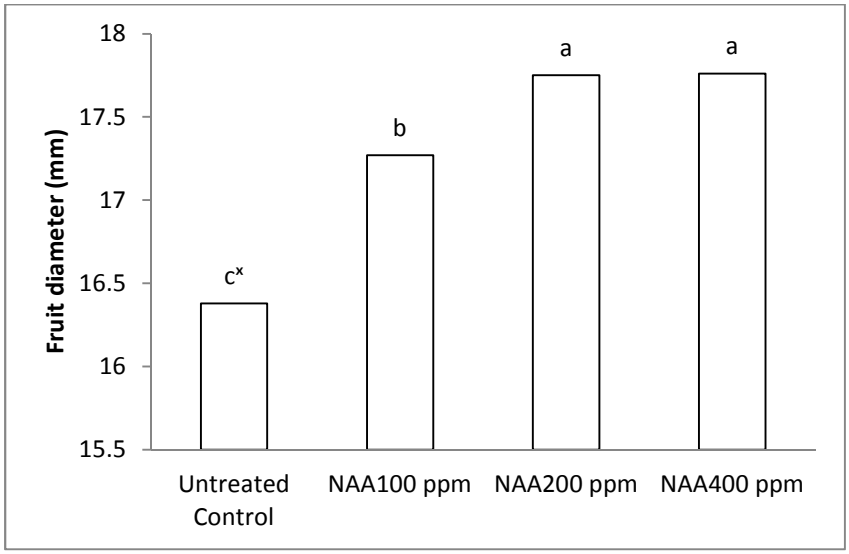


	Average of season
Pr > F	
Treatment	*<0.0001*
NAA vs Control	*<0.0001*
NAA Lin	*0.0026*
NAA Quad	*0.0757*

[NS] *no significant differences between treatments*

[x] *means with different letters differ significantly at p<0.05*

Figure 2: The effect of NAA application in 2008/2009 on fruit weight of 'Manzanillo' olives in the season of application.

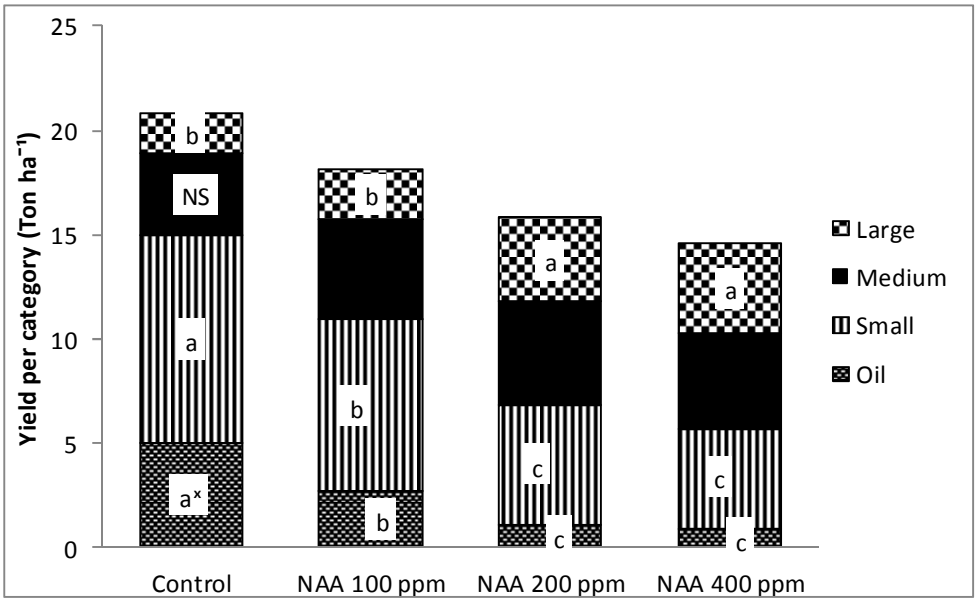


	Average of season
Pr > F	
Treatment	*<0.0001*
NAA vs Control	*<0.0001*
NAA Lin	*0.0172*
NAA Quad	*0.0475*

NS no significant differences between treatments

δ means with different letters differ significantly at p<0.05

Figure 3: The effect of different NAA concentrations on the fruit diameter of 'Manzanillo' olives in the year of application.

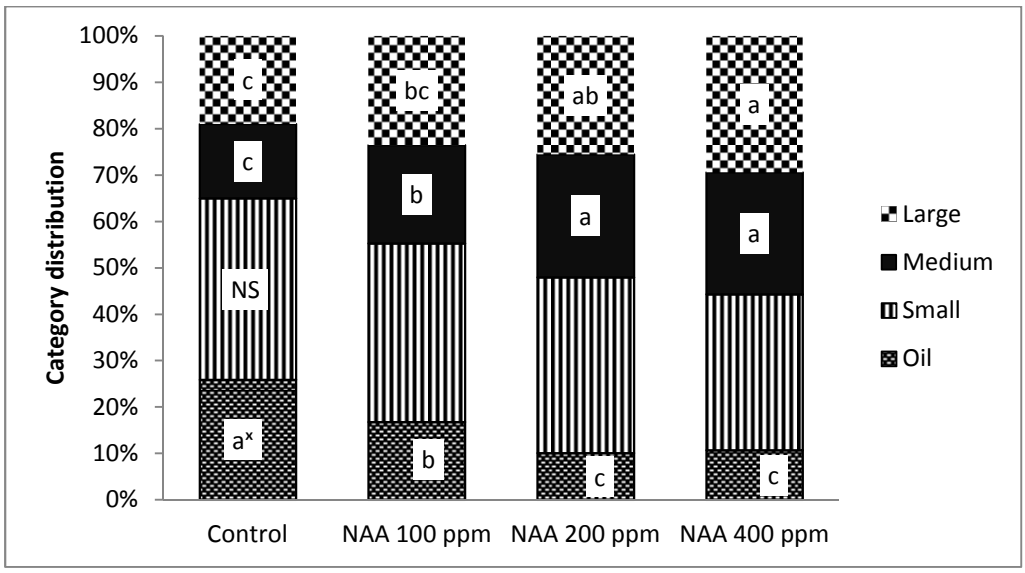


	Oil	Small	Medium	Large
Pr > F				
Treatment	*<0.0001*	*<0.0001*	*0.2647*	*<0.0001*
NAA vs Control	*<0.0001*	*<0.0001*	*0.0638*	*0.0001*
NAA Lin	*0.0044*	*0.0001*	*0.6204*	*0.0007*
NAA Quad	*0.0516*	*0.0344*	*0.6515*	*0.0324*

[NS] *no significant differences between treatments*

[x] *means within a fruit size category with different letters differ significantly at p<0.05*

Figure 4: The effect of NAA application in 2008/2009 on yield per category of 'Manzanillo' olives in the season of application.

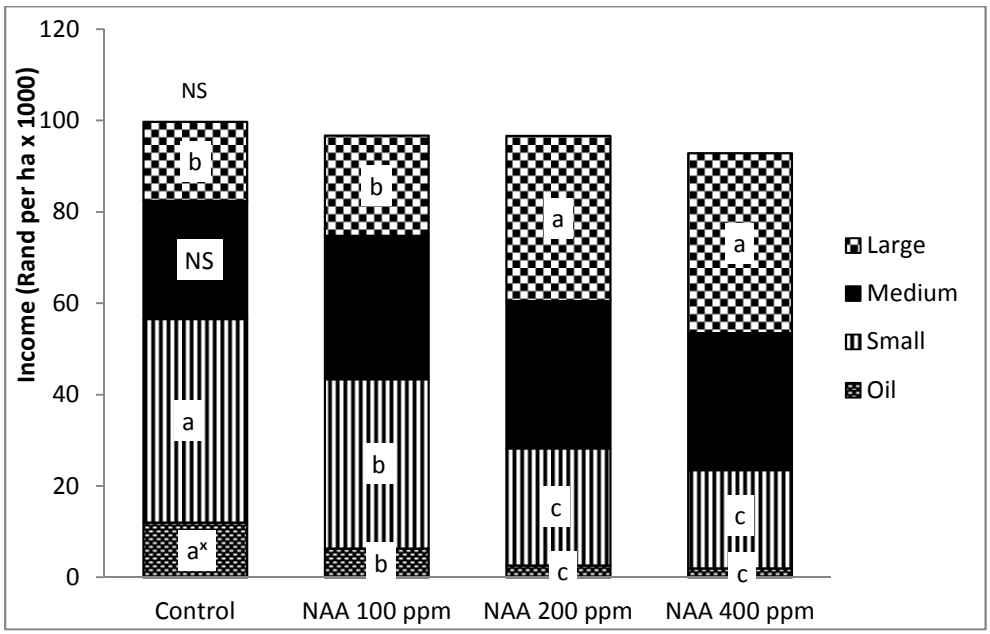


	Oil	Small	Medium	Large
Pr > F				
Treatment	*<0.0001*	*0.2586*	*<0.0001*	*0.0074*
NAA vs Control	*<0.0001*	*0.3244*	*<0.0001*	*0.0036*
NAA Lin	*0.0560*	*0.0902*	*0.0201*	*0.0403*
NAA Quad	*0.0509*	*0.6894*	*0.0315*	*0.9853*

NS no significant differences between treatments

x means within a fruit size category with different letters differ significantly at p<0.05

Figure 5. The effect of NAA application in 2007/2008 on category distribution of 'Manzanillo' olives in the season of application.

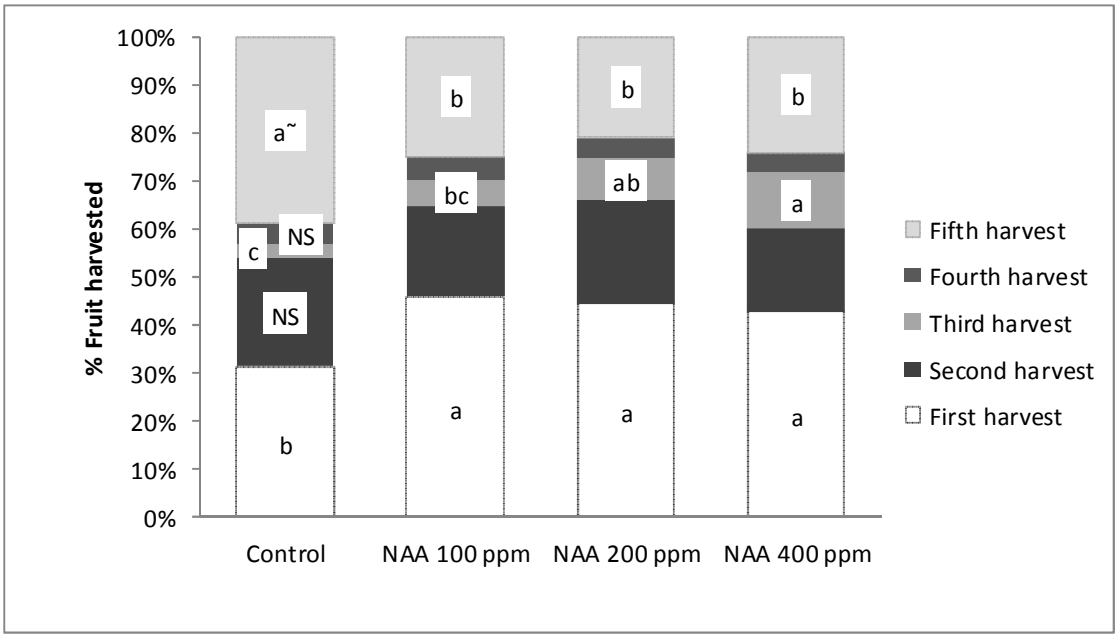


	Oil	Small	Medium	Large	Total income
Pr > F					
Treatment	*<0.0001*	*<0.0001*	*0.2647*	*<0.0001*	*0.7096*
NAA vs Control	*<0.0001*	*<0.0001*	*0.0638*	*0.0001*	*0.3729*
NAA Lin	*0.0044*	*0.0001*	*0.6204*	*0.0007*	*0.4776*
NAA Quad	*0.0516*	*0.0344*	*0.6515*	*0.0324*	*0.8197*

[NS] *no significant differences between treatments*

[x] *means within a fruit size category with different letters differ significantly at p<0.05*

Figure 6: The effect of NAA application in 2007/2008 on income per category of 'Manzanillo' olives in the season of application.



	First harvest	Second harvest	Third Harvest	Fourth Harvest	Fifth Harvest
Pr > F					
Treatment	*0.0062*	*0.4730*	*0.0068*	*0.9701*	*0.0016*
NAA vs Control	*0.0007*	*0.2983*	*0.0095*	*0.8953*	*0.0002*
NAA Lin	*0.4498*	*0.4659*	*0.0132*	*0.6545*	*0.9726*
NAA Quad	*0.8903*	*0.3479*	*0.6179*	*0.8914*	*0.3519*

^{NS} *no significant differences between treatments*

~means *with different letters differ significantly at p<0.05*

Figure 7: The effect of NAA application in 2007/2008 on harvest distribution of 'Manzanillo' olives in the season of application.

Paper 4. Effect of GA_3 application during the "off" season on yield and fruit quality of 'Manzanillo' and 'Mission' olives in the following "on" season.

Abstract. Olive trees are prone to alternate bearing. Gibberellins (GA) produced by the seed of developing fruit in an "on" season is thought to repress flower initiation resulting in a poor bloom in the subsequent "off" season. Application of gibberellic acid (GA_3) during the "off" season may decrease flower initiation and thereby decrease yield in the following season, which would otherwise have been an "on" season. The aim of this research was to investigate the timing of flower intiation in olive trees in the Western Cape of South Africa and to determine the optimal timing of GA_3 application in an "off" season to reduce yield alternation. GA_3 was applied to 'Mission' at 200 to 400 mg L^{-1} from January to June in the 2007/2008 season and at 500 to 1500 mg L^{-1} from December to February in the 2008/2009 season. GA_3 application to 'Mission' in 2007/2008 had no effect on the return bloom. No results were generated after application to 'Mission in 2008/2009 since none of the trees in the orchard or in adjacent orchard flowered. The lack of a bloom was possibly due to inclement climatic conditions that prevented flower initiation or caused dedifferentiation. In 2009/2010, GA_3 at 400 mg L^{-1} was applied to 'Manzanillo' in December, February and March. GA_3 application to 'Manzanillo' in the 2009/2010 season significantly reduced flower abundance and yield while increasing fruit size in the following 2010/2011 "on" season. Application in December 2009 was particularly effective and also decreased flower numbers compared to the later application dates. Therefore, application during endocarp sclerification seems to be most effective, as found in the Northern hemisphere. However, contrary to previous findings, application in February and March after endocarp sclerification also decreased the flower abundance in the following season. The lower yields in 2010/2011 induced by GA_3 application did not affect flowering in the 2011/2012 season as even the control treatment had an abundance of flowers. The 2011/2012 crop still needs to be assessed.

Introduction

Olive trees are well known for their yield alternation in subsequent seasons (Lavee and Avidan, 1994). Flowers are produced exclusively on the previous season's shoots (Krueger *et al.,* 2004). "On" season trees carrying excessive crop loads form fewer reproductive buds resulting in a subsequent "off" season with very low crop loads (Baktir et. al., 2004).

Flower induction (FI) in olive commences in mid-summer, as early as seven to eight weeks after full bloom at approximately the same time of endocarp sclerification (pit hardening) of the current season's fruit (Baktir et al., 2004; Fernandez-Escobar et al., 1992; Sanz-Cortés et al., 2002). The number of seeds present on olive trees correlates negatively with the extent of flower initiation (Stutte and Martin, 1986). FI in olives, as in various other fruit crops (Monselise and Goldschmidt, 1982), is thought to be suppressed by gibberellic acids (GAs) released by the developing seeds (Stutte and Martin, 1986; Lavee, 1996; Fabbri and Benelli, 2000).

Baktir et al. (2004) found that GA_3-like substance levels in leaves, shoot nodes and shoot tips of olive trees were higher in "on" than in "off" seasons. Furthermore, Fernandez-Escobar et al. (1992) showed that scaffold injections of GA_3 applied during endocarp sclerification (May to June in the Northern Hemisphere) to non-bearing olive trees reduced flowering the following year. The same study revealed that the removal of fruit (i.e. removal of the GA source) after endocarp sclerification did not affect flowering abundance the following year. Similar to olive trees, GA_3 application during early fruit development decreases flower numbers in apple (Prang et al. 1998) and peach (Taylor and Geisler-Taylor, 1998) trees, while application during the winter months to 'Hass' avocado trees (Salazar-Garcia and Lovatt, 1999) also decreases flower numbers in the following year.

GA_3 application in December (mid-summer in the Southern Hemisphere) decreased flower bud density of unbranched 'Redhaven' and 'Cresthaven' peach shoots (Taylor and Geisler-Taylor, 1998). However, application from early January untill late April was not effective. GA_3 application 6 weeks after full bloom significantly reduced the percentage of fruiting spurs as well as fruit set and also increased the percentage of vegetative spurs and lateral buds in apple (Mostafa and Saleh, 2006). GA_3 application 5 weeks after full bloom reduced flower numbers in 'Elstar' and 'Golden Delicious' apple (Prang et al. 1998), while GA_3 application in summer/autumn in 'Anna' apple had no effect on return bloom (Mostafa and Saleh, 2006). Evidently, the effectiveness of GA_3 depends on the timing of application.

We conducted an experiment to determine when flower initiation occurs in 'Mission' and 'Manzanillo' olives in South Africa and also to assess whether "off" season GA_3 application

can be used to decrease yield in the subsequent "on" season, thereby improving fruit quality and decreasing yield alternation.

Materials and Methods

Experiments were conducted in the 2007/2008, 2008/2009 and 2009/2010 seasons in Paarl (Latitude 33°42'S, Longitude 19°02'E) in the Mediterranean-type climate Western Cape Province of South Africa.

Experiment 1

GA_3 (ProGibb® 40%, Valent BioSciences Corporation, Libertyville, USA) was applied at 200 or 400 mg L^{-1} on 4 January, 29 February, 24 April or 25 June 2008 in an 'Mission' orchard established in 1993 at a 9 x 4.5 m spacing. Trees have an average canopy volume of 40 m^3. Previous yields recorded for this orchard was 7.8 and 0.5 ton ha^{-1} in the 2006/2007 and 2007/2008 seasons respectively. GA_3 was applied to "off" trees that were expected to have a heavy bloom in the following season. Treatments, including an untreated control, were randomized in seven blocks with two trees per plot and with guard trees between plots and guard rows between treatment rows. Application was done on wind still mornings with a truck-mounted motorized sprayer until run off. Each tree received ca. 6 L of the spray mixture. Foliwett (Foliwett 900, Gouws & Scheepers (Pty) Ltd., Witfield, RSA) (a.i. 940 g L^{-1} alkylated phenyl-ethylene oxide) was included in the spray application as wetting agent at 3 ml per 100 L water.

Return bloom and flower quality.

Three one-year-old shoots of about 25 cm long per tree were randomly selected before flowering and the number of racemes per shoot was determined at full bloom (FB). Trees were scored visually at FB (14 October 2008) from 0 to 5, where 0 represents zero flowers and 5 represents a very heavy bloom. Five racemes per tree (i.e., ten racemes per plot) were randomly selected at FB and brought to our laboratory where the number of flowers per raceme were counted. The quality of these flowers, i.e., whether perfect or staminate, was subsequently determined using a light microscope (Kyowa stereo microscope, model SD-2PL from Kyowa Optical CO., LTD. Tokyo, Japan).

Fruit quality and yield at harvest.

The first selective harvest, according to 'Mission' table olive size and colour specifications, was done on 6 May 2008. The second harvest for table olives occurred on 29 June 2008 and the remaining green fruit were harvested the next day. The proportion of the crop that was black was determined. All the fruit of each tree were weighed to determine yield in kg per tree, subsequently converted to ton ha^{-1}. A 20-fruit sample per tree at each harvest date was used to determine average fruit and pip diameter (measured by electronic calliper), the pip-to-flesh ratio and average fruit mass. Fruit number per tree was estimated by dividing the total fruit mass per tree by the average fruit mass of the 20-fruit sample.

Experiment 2

Four GA_3 treatments and an unsprayed control were compared in a 'Mission' orchard established in 1982 at a 9 x 4.5 m. Trees have an average canopy volume of 40 m^3. Previous yields recorded from this orchard were 3 and 2 ton ha^{-1} in the 2006/2007 and 2007/2008 seasons respectively. GA_3 was applied at 500 mg L^{-1} on either 15 December 2008, 16 January 2009 or 13 February 2009 while the fourth GA_3 treatment received 500 mg L^{-1} GA_3 on each of these three dates. GA^3 was applied to "off'' trees that were expected to have a heavy bloom the following season. The four GA_3 treatments and an unsprayed control treatment were randomised in seven blocks with two trees per plot and with guard rows between treatment rows and guard trees between plots. Spray treatments were applied as in Experiment 1.

Return bloom.

Return bloom was visually assessed at FB (26 October 2009) as described for Experiment 1. Raceme number and flower quality were not assessed.

Experiment 3

GA_3 was applied at 400 mg L^{-1} on 24 December 2009, 3 February 2010 or 08 March 2010 in a 'Manzanillo' orchard that was planted in 1993 at 7 x 4.5 m. Trees have an average canopy volume of 28 m^3. GA_3 was only applied to "off'' trees that were anticipated to have a heavy bloom the following season. The three GA_3 treatments and an unsprayed control

treatment were randomised in eight blocks with two trees per plot and with guard rows between treatment rows and guard trees between plots. Spray treatments were applied as in Experiment 1.

Flower in ''on'' year and return bloom the subsequent year.

Trees were scored visually at FB (11 October 2010) where the extent of flowering was rated from zero to 100%. Raceme number and flower quality were not assessed. Return bloom (season 2010/2011) was measured at FB (4 October 2011).

Fruit quality at harvest.

Only fruit that were black were picked during the first selective harvest on 23 February 2011. All the remaining green fruit were harvested on 1 March 2011. The fruit of each tree were weighed, yield in kg per tree was determined and subsequently converted to ton ha^{-1}. A 15-fruit sample per tree was randomly collected on both harvest dates to determine average fruit and pip diameter (measured by electronic calliper), the pip-to-flesh ratio, average fruit mass and the percentage black and green fruit.

Statistical analysis.

Data was analysed with the General Linear Models (GLM) procedure of the SAS (Statistical Analysis System) computer program (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC., USA).

Results

Experiments 1 and 2

For 'Mission' no significant treatment effects were found for any of the variables measured, i.e., extent of flowering, fruit quality or yield (data not presented).

Experiment 3

Extent of bloom in the "on'' season: GA_3 application to 'Manzanillo' in January and February 2010 decreased the extent of flowering in October 2010 by 25 to 30% compared to

the control while GA_3 application in December 2009 decreased the extent of flowering by 57% compared to the control (Table 1). GA_3 application in December significantly decreased the extent of flowering compared to application in January or February. GA_3 treatments equally decreased the number of fruit per tree at harvest (Table 1).

Harvest distribution: Treatments did not differ in the percentage of the crop that was harvested black (Figure 1).

Fruit quality and yield: GA_3 application in 2009/2010 season significantly decreased the 2010/2011 yield of green and black fruit as well as total yield compared to the control (Figure 2). There was no difference in yield between GA_3 treatments. GA_3 application in December significantly increased the weight of green fruit compared to other treatments and average fruit weight of the entire crop compared to the control (Figure 3). GA_3 application in March also increased the weight of green fruit compared to the control. GA_3 application in December seemed to increase the diameter of green fruit compared to the untreated control although treatment differences were not significant ($p = 0.0587$) (Figures 4). GA_3 did not affect the pip to fruit diameter ratio (Table 1).

Return bloom: No significant differences were found in the extent of flowering, which was abundant for all treatments (Table 1).

Discussion

Olive growers are constantly battling the genetic predisposition of olive trees to alternate bearing (Krueger et al., 2004). The number of seeds present on olive trees correlates negatively with the degree of flower initiation (FIN) (Stutte and Martin, 1986). FIN in olives is thought to be inhibited by GAs that are released by the developing seeds at the time of endocarp sclerification (pit hardening) (Fabbri and Benelli, 2000; Lavee, 1996; Stutte and Martin, 1986).

Fernandez-Escobar et al. (1992) previously found that scaffold injections of GA_3 during endocarp sclerification (May to June in the Northern Hemisphere) to non-bearing olive trees reduced flowering the following season. Applications after endocarp sclerification was not

effective. The authors furthermore found that seed destruction and fruit removal (removal of GA source) improved return bloom only when done at endocarp sclerification.

In the first season in 'Mission', GA_3 application at 200 and 400 mg L^{-1} from January to June had no effect on any of the variables measured while in the third season on 'Manzanillo', GA_3 application at 400 mg L^{-1} from December to March decreased return bloom and yield. Considering the above, the ineffectiveness of GA_3 in the first season can not be ascribed to the concentrations applied or the timing of applications. While it is possible that 'Mission' is less responsive to GA_3, it is equally likely that climatic conditions between flower initiation and full bloom anulled any differences that may have been present between treatments. As a point in this case, there was no return bloom for any of the treatments applied in the second season. This complete lack of a return bloom was likely due to climate conditions experienced between flower initiation and full bloom as trees were supposed to experience an "on" bloom following on the preceding "off" season. In this particular season, none of the olive orchards adjacent to the trial orchard showed a return bloom, which further strengthens the hypothesis that climatic conditions influenced flower differentiation and therefore the results of this trial. Lavee (1996) suggested a two-step theory for olive flower bud differentiation according to which buds receive their initial induction for differentiation during summer while a second stimulus is required during winter. Differentiation will only occur if inductive conditions prevail in both seasons (Lavee, 1996).

In the third season, application of GA_3 in December 48 days after full bloom (at the time of endocarp sclerification), dramatically decreased flower abundance in the "on" season compared to the unsprayed control. However, later application in February and March also decreased flower initiation compared to the control. Although flower induction in olives peak during endocarp sclerification (May to June in the Southern Hemisphere) (Baktir et al., 2004; Fernandez-Escobar et al., 1992; Sanz-Cortés et al., 2002), buds that form later may also give rise to flowers. At flowering in spring, reproductive buds in olive may be three to eight months old (Lavee, 1996). It follows that while GA_3 application to inhibit flower initiation may be most effective during endocarp sclerification, later application may repress flower initiation in more distal buds on shoots that only become responsive to inductive signals after endocarp sclerification. Buds in the axils of the most distal leaves (growth that occurred just before winter) normally does not undergo floral differentiation (Lavee, 1996) and application

at this stage should prove ineffective. However, in peach, GA_3 application in autumn also decreased flowering in spring by inducing abortion of flowers (Painter and Stembridge, 1972). It is possible that GA_3 application may have a similar effect on flower buds in olive.

Despite a significant increase in the size of 'Manzanillo' olives in response to application of GA_3 in December and February, the increase in fruit size was not sufficient to offset the severe reduction in fruit numbers. In addition, despite a considerable decrease in fruit number, GA_3 application in March did not significantly increase fruit size compared to the control. Although GA_3 application in December increased the proportion of black fruit as percentage of the total crop by 16% compared to the control, the treatment effect was not significant. An increase in the proportion black fruit indicates that maturity was advanced as fruit turn black during ripening. Since 'Manzanillo' olives should be harvested green, harvesting of GA_3-treated trees should have been done sooner.

Although the return bloom in the 2011/12 season was abundant for all treatments, flower quality and raceme number were not assessed. Therefore, the 2011/12 crop should be assessed in case the lower 2010/2011 yields of the GA_3 treatments improved flower quality compared to the control.

Conclusions

The efficacy of GA_3 in decreasing flower initiation in 'Manzanillo' when applied in December to March suggests that flower initiation takes place at this time. However, further work at lower GA_3 concentrations and over an extended period is required to determine effective concentrations of GA_3 and the timing of flower initiation, also for other cultivars grown in South Africa. The location of racemes on shoots of treated trees relative to the time of growth cessation of these shoots and comparative to control trees should also give an indication of the time of flower initiation.

"Off" season application of GA_3 to decrease yield alternation may have a commercial use when an excessive crop is expected following on a very low yield. However, the practicality of using GA_3 to decrease yield alternation is curtailed by its early application, at a time when it is unknown whether external factors, i.e., climatic conditions during winter and during fruit set, will negatively influence flower and fruit numbers.

Literature cited

Baktir, I., Ulger, S. & Kaynak, L., 2004. Relationship of seasonal changes in endogenous plant hormones & alternate bearing of olive trees. HortScience. 39: 987-990.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Fernández-Escobar, R., Benlloch,M., Navarro,C. & Martin, G.C., 1992. The time of floral induction in olive. J. Am. Soc. Hort. Sci. 117: 304-307.

Krueger, W.H., Maranto, J. & Sibbett, G.S., 2004. Olive fruit thinning. In: Olive Production Manual. Sibbett, G.S. & Ferguson, L. (Eds.) Pp. 101-104. University of California, Agriculture and Natural Resources Publication 3353, Oakland, California, USA.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Lavee, S. & Avidan, N., 1994. Protein content and composition of leaves and shoot bark in relation to alternate bearing of olive trees (*Olea europaea L.*). Acta Hort., 356: 143-147.

Monselise, S.P. & Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. Hort. Rev. 4: 128-173.

Mostafa, E.A.M. & Saleh, M.M.S., 2006. Influence of spraying with gibberellic acid on behaviour of Anna apple trees. J. Appl. Sci. Res., 2(8): 477-483.

Painter, J. W. & Stembridge, G.E., 1972. Peach flowering response as related to time of gibberellin application. HortScience. 7(4): 389-391.

Prang, L., Stepban, M., Schneider, G., Bangerth, F., Guardiola, J.L. and Martinez, G. 1998. Gibberellin signals originating from apple fruit and their possible involvement in flower induction. Acta Hort., 463: 235-241.

Salazar-Garcia, S. & Lovatt, C.J., 1999. Winter injections of gibberellic acid altered the fate of 'Hass' avocado buds: Effects on inflorescence type, number and rate of development. J. Hort. Sci. & Biotech. 74(1): 69-73.

Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., & Meier, U., 2002. Phenological growth stages of olive trees (*Olea europaea*). Ann. Appl. Biol. 140: 151-157.

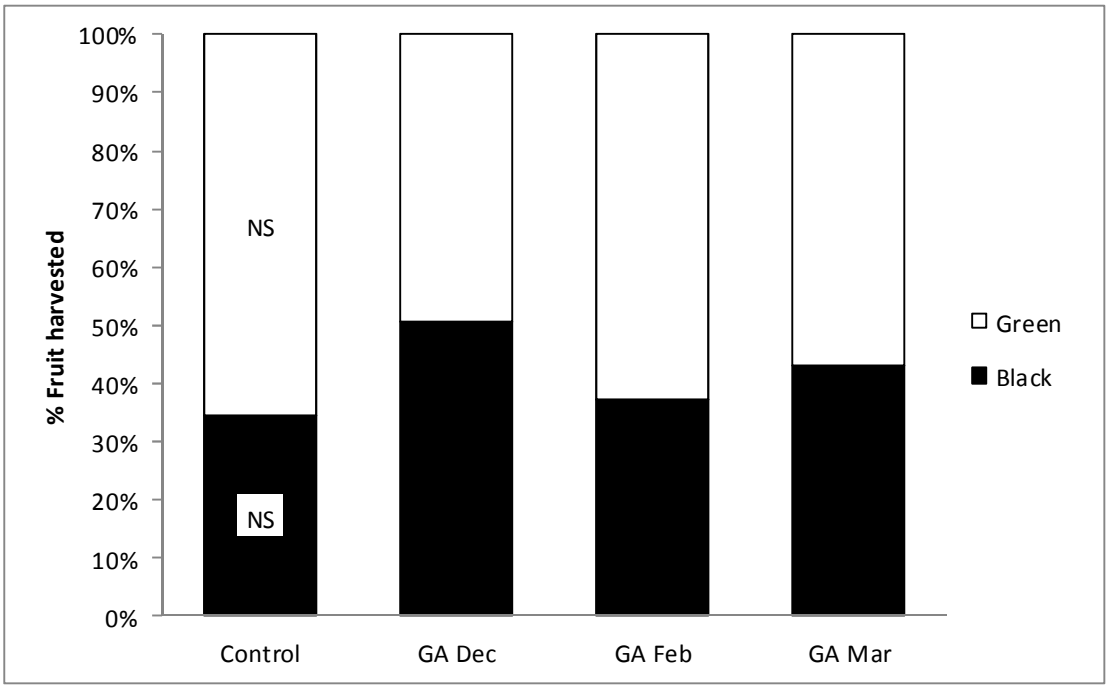
Stutte, G.W. & Martin, G.C., 1986. Effect of killing the seed on return bloom of olive. Sci Hort. 29: 107-113.

Taylor, B.H. & Geisler-Taylor, D., 1998. Flower bud thinning and winter survival of 'Redhaven' and 'Cresthaven' peach in response to GA_3 sprays. J. Amer. Soc. Hort. Sci. 123(4): 500-508.

Table 1. The effect of GA_3 application during the 2009/2010 "off" season on flowering in the 2010/2011 "on" season, pip to fruit diameter ratio, estimated fruit number and return bloom of 'Manzanillo' olives. Means were separated by LSD (5%).

Treatment	''On'' flower[x]	Average pip:fruit diameter	Estimated fruit number per tree	Return bloom
Control	81 a [z]	0.470 NS	5342 a	96 NS
GA Dec	18 c	0.460	1045 b	98
GA Feb	57 b	0.470	2442 b	98
GA Mar	51 b	0.473	1724 b	97
Pr > F				
Treatment	*<0.0001*	*0.2725*	*0.0009*	*0.3817*

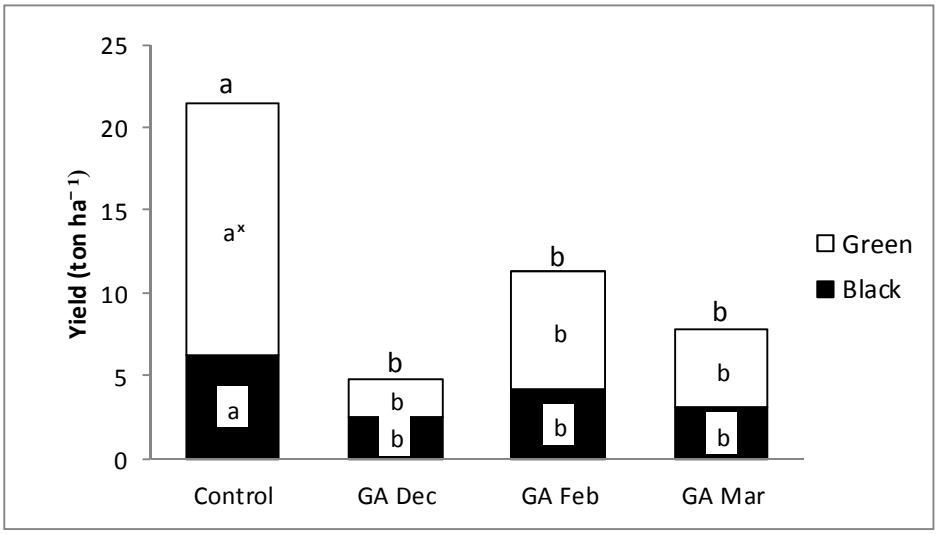
[NS] *no significant differences between treatments*
[z] *means with different letters differ significantly at p<0.05*
[x] *Subjective score out of 100.*



Pr > F	% Black fruit
Treatment	*0.2501*

NS no significant differences between treatments

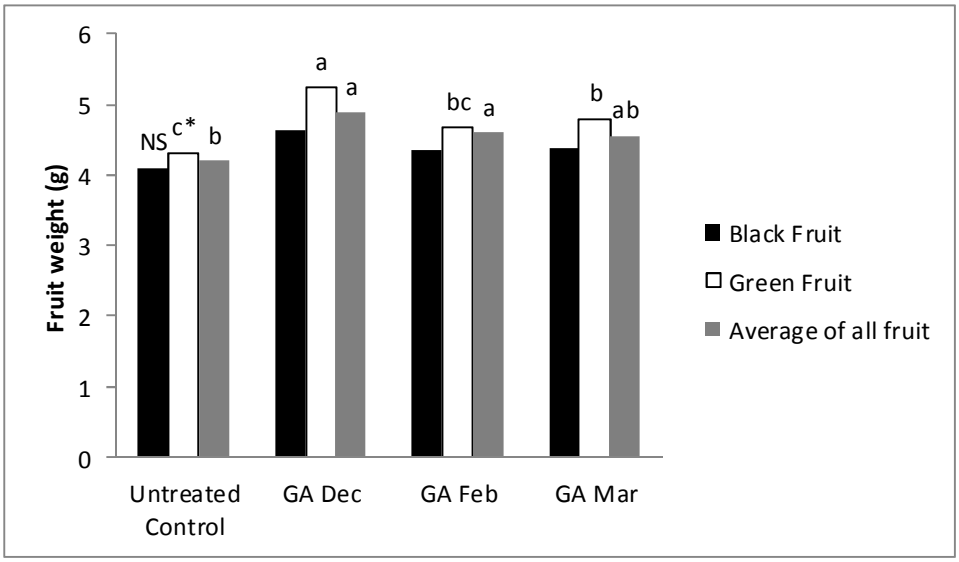
Figure 1. The effect of GA_3 application during the 2009/2010 "off" season on fruit colour distribution of 'Manzanillo' olives in the following 2010/2011 "on" season.



Pr > F	Black	Green	Total yield
Treatment	*0.0074*	*0.0009*	*0.0004*

[x] *means with different letters differ significantly at p<0.05*

Figure 2. The effect of GA_3 application during the 2009/2010 "off" season on yield of 'Manzanillo' olives in the following 2010/2011 "on" season.

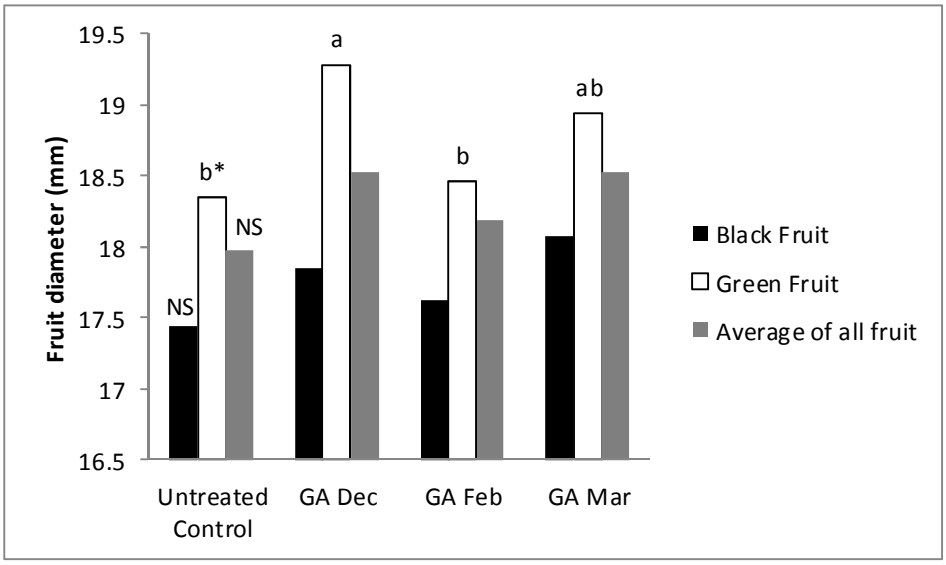


Pr > F	Black Fruit	Green Fruit	Average of all fruit
Treatment	*0.0919*	*0.0009*	*0.0144*

NS no significant differences between treatments

** means within a harvest date with different letters differ significantly at p<0.05*

Figure 3. The effect of GA_3 application during the 2009/2010 "off" season on average fruit weight of 'Manzanillo' olives in the following 2010/2011 "on" season.



Pr > F	Black Fruit	Green Fruit	Average of all fruit
Treatment	*0.3923*	*0.0587*	*0.2923*

NS no significant differences between treatments

** means within a harvest date with different letters differ significantly at p<0.05*

Figure 4. The effect of GA_3 application during the 2009/2010 "off" season on average fruit diameter of 'Manzanillo' olives in the following 2010/2011 "on" season.

GENERAL DISCUSSION AND CONCLUSIONS

Alternate bearing is a fundamental problem in the olive industry. A better understanding of the reproductive phenology of the olive under South African conditions is essential in order to address this problem. Knowledge on the timing of floral initiation and differentiation as well as the factors that repress these processes is needed to address problems such as poor flowering and alternate bearing in general. Previous work indicated that flower induction (FI) in olive commences in mid-summer, as early as seven to eight weeks after full bloom at approximately the same time as endocarp sclerification (pit hardening) of the current season's fruit (Baktir et al., 2004; Fernandez-Escobar et al., 1992; Sanz-Cortés et al., 2002). The number of seeds present on olive trees correlates negatively with the extent of flower initiation (Stutte and Martin, 1986). FI in olives, as in various other fruit crops (Monselise and Goldschmidt, 1982), is thought to be inhibited by gibberellic acids (GAs) released by the developing seeds (Fabbri and Benelli, 2000; Lavee, 1996; Stutte and Martin, 1986).

GA_3 was applied during summer to 'Manzanillo' olives to establishment when seed-produced GA is most inhibitory to reproductive development. GA applied in December of the 2009/2010 "off" season reduced flower numbers in the 2010/2011 "on" season significantly when compared to other application timings and to the untreated control. However, the increase in fruit quality did not compensate for the major loss in yield. Contrary to previous research (Fernandez-Escobar et al., 1992), GA_3 application after pit hardening in February and March also significantly decreased flower numbers. Although the use of GA as a commercial tool to reduce yield alternation might be impractical, this research helped us to understand the nature of the reproductive development of the olive in the Western Cape region of South Africa. Since knowing that GA negatively influences reproductive development during the time of endocarp sclerification, application of a gibberellin synthesis inhibitor at this time in an "on" season should be investigated in future trials. Hedden and Graebe (1985) indicated that application of a gibberellin synthesis inhibitor might counteract the negative effects of seed-derived GAs on flower induction.

Actions aimed at ensuring consistent adequate yields of high quality fruit should ensure the presence of enough bearing wood and moderation of fruit (or rather number of seeds) on the tree. The quality of table olives is determined by size and colour for black table cultivars

such as 'Mission, whereas fruit quality in green table olives is determined only by size. . The value of most table olives increases with an increase in fruit size. The excessive crop loads of "on" seasons results in the production of large numbers of small fruit and, in the case of 'Mission', fruit remain green. Green 'Mission' fruit and small fruit of the other table olive cultivars can only be used for oil. It can be concluded that the value of the crop increases when bigger fruit are produced on average. Considering the above, our aim was to decrease the number of fruit and increase fruit quality in the same season and to prevent a subsequent "off" season. This should increase the total income over two seasons and ameliorate the negative effects of alternate bearing.

Naphthalene acetic acid (NAA) has been used in other countries to thin oil and table olives. However, NAA has not been used in South Africa and effective concentrations for local conditions and cultivars were not known. Previous research showed that NAA application consistently decreases the number of fruit per tree and increases fruit size (Martin et al., 1980). Despite the decrease in yield in response to NAA application, the value of the crop and the income per hectare may increase due to the increase in fruit size and a decrease in harvesting costs (Krueger et al., 2002). NAA was applied at concentrations of 100 to 400 mg L^{-1} to 'Mission', 'Manzanillo' and 'Barouni' to determine the efficacy of NAA and to establish optimum concentrations under South African conditions. Application of 100 to 200 mg L^{-1} NAA to heavy bearing (~20 ton ha^{-1}) 'Barouni' trees in the 2007/2008 season significantly increased fruit quality. However, the decrease in yield (only 16%) was not of sufficient extent to affect return bloom in 2008/2009, possibly as a result of insignificant seed reduction. Stutte and Martin (1986) concluded that the number of seeds present on olive trees correlates negatively with the extent of flower initiation. The effect of NAA on fruit number was also not of sufficient extent to increase vegetative growth and thereby create more potential bearing sites for the next season.

Higher NAA concentrations were applied the next season to 'Manzanillo' and 'Mission' and a satisfactory level of thinning was achieved at concentrations of 200 to 400 mg L^{-1}. It seems that higher NAA concentrations are needed for a similar level of thinning under South African conditions when compared to results obtained in California (Krueger et al., 2004). Dag et al. (2009) found that NAA at 100 mg L^{-1} significantly decreased fruit numbers in 'Barbea' and 'Picual' cultivars when applied at 10 days after full bloom (dafb). Considering

our results that indicated that relatively higher NAA concentrations is needed to achieve a similar thinning severity as in California, earlier NAA application should be considered in future under South African conditions.

Over-thinning can lead to unnecessary loss of income. According to Dag et al. (2009), the optimum number of fruit per canopy volume should be established to achieve the required balance between the current crop, vegetative growth (bearing positions for return bloom) and processes that promote the following reproductive cycle. Previous work by Dag et al. (2009) showed that a high level of fruit thinning increased fruit quality in the year of application, but also significantly increased the return bloom in the following season thereby decreasing yield alternation. Unfortunately, the effect of NAA on yield alternation could not be established in any of our trials due to very erratic bloom. It appears that some external factor has a major overriding effect on reproductive development under local conditions with the result that an "off" season might be followed by another "off" season or that no increase in flowering is achieved despite considerable fruit thinning in the "on" season.

Future research on the effect of climate conditions – most notably, temperature - on reproductive development is needed for South African olive cultivars. Previous research has shown that climatic conditions during summer and winter affect reproductive development in olive (Lavee, 1996). It might be worthwhile to compare climatic data of olive production regions in South Africa to the major olive growing regions in the world where the same cultivars are successfully grown.

Literature cited

Baktir, I., Ulger, S. & Himelrick, D.G., 2004. Relationship of seasonal changes in endogenous plant hormones and alternate bearing of olive trees. HortScience. 39: 987-990.

Dag, A., Bustan, A., Avni, A., Lavee, S. & Riov, J., 2009. Fruit thinning using NAA shows potential for reducing biennial bearing of 'Barnea' and 'Picual' oil olive trees. Crop Pasture Sci. 60: 1124-1130.

Fabbri, A. & Benelli, C., 2000. Flower bud induction and differentiation in olive. J. Hort. Sci. Biotech. 75: 131-141.

Fernández-Escobar, R., Benlloch, M., Navarro, C. & Martin, G.C., 1992. The time of floral induction in olive. J. Am. Soc. Hort. Sci. 117: 304-307.

Hedden, P. & Graebe, J.E., 1985. Inhibition of giberellin biosynthesis by paclobutrazol in cell-free homogenates of Cucurbita maxima endosperm and Malus pumila embryos. J. Plant. Growth Reg. 4: 111-122.

Krueger, W.H., Heath, Z. & Mulqueeney, B. 2002. Effect of spray solution concentration, active ingredient, additives and sequential treatments of napthalene acetic acid for chemical thinning of Manzanillo table olives (O*lea europea*). Acta Hort. 586: 267-271.

Lavee, S., 1996. Biology and physiology of the olive. In: World Olive Encyclopaedia. Blazquez, J.M. (Ed.). Pp. 71 – 105, IOOC, Barcelona, Spain.

Martin, G.C., Lavee, S., Sibbett, G. S., Nishijima, S. & Carlson, S. P., 1980. A new approach to thinning olives. Calif. Agric. 34: 7-8.

Monselise, S.P. & Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. Hort. Rev. 4: 128-173.

Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., & Meier, U., 2002. Phenological growth stages of olive trees (*Olea europaea*). Ann. Appl. Biol. 140: 151-157.

Stutte, G.W. & Martin, G.C., 1986. Effect of killing the seed on return bloom of olive. Sci Hort. 29: 107-113.